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THESIS

PLANNING FLIGHT TRAINING FOR THE TRANSITION TO THE V-22 OSPREY

by

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September 2000

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The Department of Defense is fielding the V-22 Osprey tilt-rotor aircraft in the Marine Corps and Air Force. Marine Medium Tilt-rotor Training Squadron 204 (VMMT-204) in Jacksonville, North Carolina, is the sole Fleet Replacement Squadron (FRS) for initial V-22 training, and planners must develop pilot training schedules that support service goals without exceeding VMMT-204 resources. Currently, planners manually create FRS training schedules with monthly fidelity, guided by past analysis and personal experience. However, manual methods are cumbersome and provide few measures of resource utilization. Marine planners need a decision support tool to automate V-22 FRS scheduling, given transition guidance. This thesis introduces an optimization model that takes as input Marine Corps operational requirements, Air Force and Marine annual training goals, FRS training syllabus requirements and resources available, and a prioritization scheme to resolve conflicts between competing goals. The output is a schedule of training classes identified by unit, FRS syllabus and follow-on training, and class convening date (with half-month fidelity) over a ten-year planning horizon. The model uses Microsoft Excel to input data and automate output reports for training goals, resource utilization, and training possibilities with unscheduled resources. A ten-year training plan can be completed in about 10 minutes.

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PLANNING FLIGHT TRAINING FOR THE TRANSITION TO THE V-22 OSPREY

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ABSTRACT

The Department of Defense is fielding the V-22 Osprey tilt-rotor aircraft in the Marine Corps and Air Force. Marine Medium Tilt-rotor Training Squadron 204 (VMMT-204) in Jacksonville, North Carolina, is the sole Fleet Replacement Squadron (FRS) for initial V-22 training, and planners must develop pilot training schedules that support service goals without exceeding VMMT-204 resources. Currently, planners manually create FRS training schedules with monthly fidelity, guided by past analysis and personal experience. However, manual methods are cumbersome and provide few measures of resource utilization. Marine planners need a decision support tool to automate V-22 FRS scheduling, given transition guidance. This thesis introduces an optimization model that takes as input Marine Corps operational requirements, Air Force and Marine annual training goals, FRS training syllabus requirements and resources available, and a prioritization scheme to resolve conflicts between competing goals. The output is a schedule of training classes identified by unit, FRS syllabus and follow-on training, and class convening date (with half-month fidelity) over a ten-year planning horizon. The model uses Microsoft Excel to input data and automate output reports for training goals, resource utilization, and training possibilities with unscheduled resources. A ten-year training plan can be completed in about 10 minutes.

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DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been tested for all possible cases. While every effort is made to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional validation is at the risk of the user.

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EXECUTIVE SUMMARY

This thesis develops a new spreadsheet-based decision support tool to optimally schedule pilot training synchronously with the introduction of the V-22 Osprey. The goal is to automatically prescribe an optimal ten-year schedule given projections of resources and requirements, and to alleviate tedious and time-consuming manual scheduling that lacks an objective means of assessing solution quality, and cannot reasonably be expected to be performed over a long time horizon. We expect planners to want to manually manipulate an optimal schedule, so we provide spreadsheet tools that support such excursions.

The Department of Defense is fielding the V-22 Osprey tilt-rotor aircraft in the Marine Corps and Air Force in FY 2001, and there are numerous operational and manpower requirements to meet while doing so. Marine Medium Tilt-rotor Training Squadron Two Zero Four (VMMT-204) in Jacksonville, North Carolina, is the sole Fleet Replacement Squadron (FRS) for initial V-22 training in the Department of Defense. Planners must develop pilot training schedules that support service goals without exceeding VMMT-204 resources, principally aircraft flight hours, simulator hours, and instructor pilot training events.

There are three main transition requirements: Marine Corps operational requirements, Marine Corps manpower requirements, and Air Force manpower requirements. The Marine Corps operational requirements are: transition CH-46E and CH-53D squadrons to the MV-22 and train them to initial core competency as defined in the Training and Readiness Manual; introduce the MV-22 into the deployment cycle and continue with MV-22 deployments thereafter; and maintain squadron manning levels at 100% of the Table of Organization once a squadron has transitioned. Marine Corps manpower requirements are: build the MV-22 pilot population in accordance with Grade Adjusted Recapitulation goals; train an appropriate number of pilots each year to satisfy Pilot Training Requirements assigned by headquarters; and ensure the FRS is manned with instructor pilots to support training needs. Air Force manpower requirements are

expressed as annual training quotas for each year. The Air Force wants the training spread evenly throughout the year.

Planners currently use various methods for developing FRS schedules to meet the requirements without exceeding FRS training capacity. Some use aggregate averages to establish aircraft and student equivalences (e.g., one aircraft equals 8.4 students per year, so 12 aircraft equals capacity for 100 students per year). SY Technology, Inc. analysis uses Gantt charts and process timelines to assess transition plans and resource availability. SY analysis proposes a ten-year training plan based upon standardized transition templates for each squadron. VMMT-204 Operations Department checks the feasibility of these templates by creating daily schedules for a typical squadron for each day of a four-month period in order to ensure the templates have not "averaged out" non-uniform resource requirements.

Despite all of the previous analysis of the V-22 transition, planners must still resort to manual spreadsheet entry and hand calculation to assess the feasibility of each proposed schedule. Planners want an automated decision support tool to *create* FRS training plans that maximally satisfy prioritized operational and manpower requirements without exceeding FRS resources. Such a tool would allow rapid response to exigent issues as the V-22 transition continues.

This thesis introduces Fleet Replacement Aircrew Training Scheduler (FRATS), a spreadsheet-based system that takes as input Marine Corps operational requirements; Air Force and Marine annual training goals; FRS and Advanced Tilt-rotor Training Unit (ATTU) syllabus requirements and FRS resources available; and a prioritization scheme to resolve conflicts between competing goals. In about 10 minutes, FRATS creates an optimal solution for the guidance and policy expressed in the input data. The output is a schedule of training classes identified by unit, FRS syllabus and follow-on training, and class convening date (with half-month fidelity) over a ten-year planning horizon. Additionally, FRATS identifies any opportunity to train additional pilots with unused resources, a report card for comparing transition goals with the FRATS solution, a detailed resource plan (with half-month fidelity) over the ten-year planning horizon, and

charts that are automatically generated to present the resource schedule in a convenient format. *The data spreadsheets also allow assessment of plans entered manually.*

The distinguishing advantage of FRATS is that it a*utomatically* follows user guidance and priorities to find an *optimal*, complete schedule among billions of candidates in less time than it currently takes that user to create a single *possible* schedule of unknown quality. Manual planning requires repeated calculations to check feasibility, whereas FRATS guarantees that its schedules follow user guidance, deals with unavoidable infeasibilities by employing the user's priorities, and self-checks its solutions with graphical diagnostic outputs. FRATS exploits the same experience and mental agility that a planner must employ to change plans for shifting priorities, changing syllabi, or adjustments to resource availability, but FRATS enhances the planner's experience with computational speed and mathematical accuracy. Finally, FRATS admits manual adjustment of schedules and provides complete diagnosis of results to assess the feasibility of each proposed schedule period.

FRATS has been used to create a baseline schedule based on data and priorities provided by Marine Corps Aviation Department, Marine Corps Department of Manpower and Reserve Affairs, Marine Corps Combat Development Command, and VMMT-204 (circa August, 2000). For this baseline scenario, the optimal FRATS solution highlights training resource deficiencies in FY 2005 and, to a lesser degree, FY 2008. In the baseline scenario, Air Force annual requirements are satisfied every year except FY 2010, when a deficit of four pilots is scheduled. Following recommendations from the Aviation Department, an excursion from the baseline scenario produces a schedule that eliminates FY 2008 deficiencies and reduces FY 2005 deficiencies significantly. Effective Staff-to-Fleet personnel rotation policies can eliminate these remaining deficiencies by reducing the number of pilots requiring FRS training.

FRATS is a useful tool for developing V-22 transition plans. It creates a detailed training schedule with half-month fidelity over a ten-year planning horizon. When training resources are insufficient, FRATS minimizes prioritized deficiencies, identifies the unsatisfied requirements, and creates a training schedule based upon user-input

priorities. FRATS follows fundamentals of Marine Corps aviation training and may be adapted easily for future weapons systems transitions.

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LIST OF ABBREVIATIONS AND ACRONYMS

ATTU	Advanced Tilt-rotor Training Unit
Bascop	Basic Copilot
Cat1-5	Category 1 through Category 5 Fleet Replacement Squadron Training and Readiness Syllabus
Expcop	Experienced Copilot
FRATS	Fleet Replacement Aircrew Training Scheduler
FRS	Fleet Replacement Squadron
GAMS	General Algebraic Modeling System
GAR	Grade Adjusted Recapitulation
IP	Instructor Pilot
MAWTS-1	Marine Aviation Weapons and Tactics Squadron One
MEU	Marine Expeditionary Unit
PTR	Pilot Training Requirement
TCCD	Training Course Control Document
T/O	Table of Organization
T&R1,8	Training and Readiness Manual, Vols. 1 and 8
USMC	United States Marine Corps
VMM	Marine Medium Tilt-rotor Squadron
VMMT-204	Marine Medium Tilt-rotor Training Squadron Two Zero Four

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I. INTRODUCTION

A. HISTORY OF THE V-22 TILT-ROTOR

In the mid 1960's, the United States Marine Corps (USMC) began flying CH-46 and CH-53 helicopters. The CH-46A was designed for medium lift requirements, and the CH-53A was designed for heavy lift requirements for the Vietnam War. Over thirty years later, the Marine Corps is still flying what are now the CH-46E and CH-53D series helicopters to fulfill medium lift requirements, with the CH-53E helicopter for heavy lift. Although they have served well, the longevity of the CH-46E and CH-53D is more a matter of circumstance than planning. By the late 1970's, the Marine Corps was planning for a new medium lift aircraft and focusing on tilt-rotor aircraft [Allega, 1977].

Figure 1. Marine Corps Medium Lift Helicopters: CH-46E and CH-53D
[from USMC, 2000]

First introduced to the Marine Corps in the 1960's, the CH-46E (left) and the CH-53 (right) helicopters have fulfilled medium lift requirements for over 30 years. Upgrades and modifications have kept these helicopters flying through every major US conflict since Vietnam. However, airframe age has accumulated and technology has evolved. The Marine Corps has decided to replace them with the V-22 tilt-rotor aircraft.

Tilt-rotor technology was developed in the mid-1950's, when Bell and Boeing both tested prototypes of tilt-rotor aircraft [Boeing, 2000]. Bell and Boeing were developing experimental aircraft that could hover, turn, and land vertically like a helicopter and also tilt rotors forward to fly like a turboprop airplane. The Marine Corps foresaw the potential of this technology for amphibious operations. Other service branches were also interested in tilt-rotor aircraft, prompting the Department of Defense

to fund the Joint Services Advanced Vertical Lift Aircraft Research and Development program in 1981 to pursue a tilt-rotor aircraft to meet the needs of all the services.

Bell and Boeing formed the Bell/Boeing team in April 1982 to develop the experimental tilt-rotor aircraft, and in April 1983, the Navy awarded the Bell/Boeing Team the principal design contract for the aircraft that is now known as the V-22. (See Figure 2.) However, Secretary of Defense Cheney cut funding for the V-22 in 1989, fearing high costs for limited return in mission capability [Cheney, 1989]. Eager to replace the CH-46E, the Marine Corps Deputy Chief of Staff for Aviation testified to Congress in FY 1990 that a medium lift replacement was the Marine Corps' number one priority [Pitman, 1990]. Funding was subsequently restored to the V-22 program, and today the Marine Corps and Air Force are preparing to introduce the V-22 to operational forces in 2001. The Navy will transition to the V-22 later. The Marine Corps will fly the MV-22 variant, the Air Force will fly the CV-22 variant, and the Navy will fly the HV-22 variant.

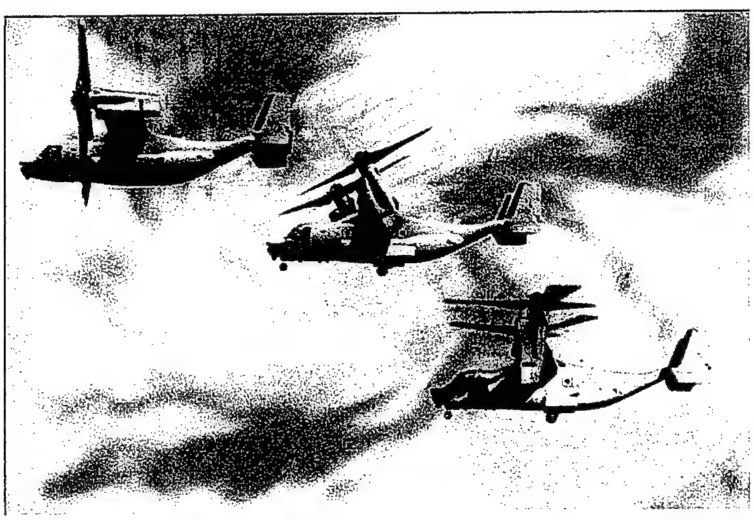

Figure 2. Bell/Boeing V-22 Osprey
[from Boeing, 2000]

The V-22 tilt-rotor aircraft is scheduled to begin replacing Marine CH-46E and CH-53D aircraft in March 2001. The V-22 is the result of research begun in the 1950's that enables an aircraft to hover like a helicopter and also rotate its engines to fly forward like a turboprop aircraft.

Comparison of capabilities between the MV-22, CH-46E, and CH-53D aircraft highlights the vast differences between these aircraft. (See Table 1.) The Marine Corps is eager to exploit these capabilities to deliver more Marines and more equipment farther and faster than previously possible, with Initial Operating Capability scheduled for mid-2001. In addition to improved flight capabilities, the V-22 incorporates the latest technological developments in communications, navigation, and environmental control systems that permit the V-22 to operate virtually anywhere. The MV-22 offers capabilities that enable new warfighting concepts at Marine Corps Combat Development Command; Operational *Maneuver From the Sea, Ship-to-Objective Maneuver*, and *Sea-based Logistics* depend upon MV-22 capabilities [MCCON, 2000]. Air Force Special Forces and Combat Search and Rescue units will employ the CV-22. The Navy foresees using the HV-22 for special warfare and fleet logistics support.

SPECIFICATION	BELL/BOEING MV-22 OSPREY	SIKORSKY CH-53D	BOEING CH-46E
Minimum Crew	2 pilots, 1 crew chief	2 pilots, 1 crew chief	2 pilots, 1 crew chief
Max Takeoff Weight	60,500 lbs.	42,000 lbs.	24,300 lbs.
Dimensions (external) length x width x height	57.3 ft x 83.7 ft x 21.7 ft	88.5 ft x 72.2 ft x 24.9 ft	84.3 ft x 51.0 ft x 16.9 ft
Maximum Internal Capacity (Troops)	24	37	24 (typically limited to 12 by power constraints)
Maximum External Lift Capacity	Single hook 10,000 lbs. Dual hook 15,000 lbs.	14,000 lbs. (typically limited to 10,000 lbs. by power constraints)	4,000 lbs.
Max velocity	275 knots	130 knots	143 knots (typically limited to 100-120 kts by power constraints)
Range	500 nm	600 nm	132 nm
Aerial Refueling Capability	Yes	No	No
Maintenance Man Hour per Flight Hour [MV-22, 1999]	10 man hours	25 man hours	15 man hours

Table 1. MV-22, CH-53D, and CH-46E characteristics

The MV-22 has a distinct advantage in speed over the older aircraft. The capability to conduct aerial refueling extends the MV-22's range and allows the aircraft to deploy worldwide without strategic airlift. MV-22 navigation and communications systems employ the latest technological advances and enhance the Marine Corps' ability to operate in "every clime and place." Additionally, the MV-22 requires 33% fewer maintenance man-hours per flight hour, which significantly reduces manpower and maintenance expenses. [USMC, 2000]

B. AGENCIES INVOLVED IN THE V-22 TRANSITION

The Marine Corps is the lead service for the V-22 transition, and the Marine Corps Aviation Department leads the planning efforts. The Aviation Department is responsible for coordinating the V-22 transition with other Marine agencies, the Navy, the Air Force, and the Bell/Boeing team. (See Figure 3.) Marine Corps V-22 representatives in Aviation Plans and Policies, Aviation Manpower Support, Aviation Logistics Support, and Aviation Weapons Procurement work together on all MV-22 transition plans. The Department of Defense will conduct all initial V-22 training at Marine Medium Tilt-rotor Training Squadron Two Zero Four (VMMT-204) in Jacksonville, North Carolina.

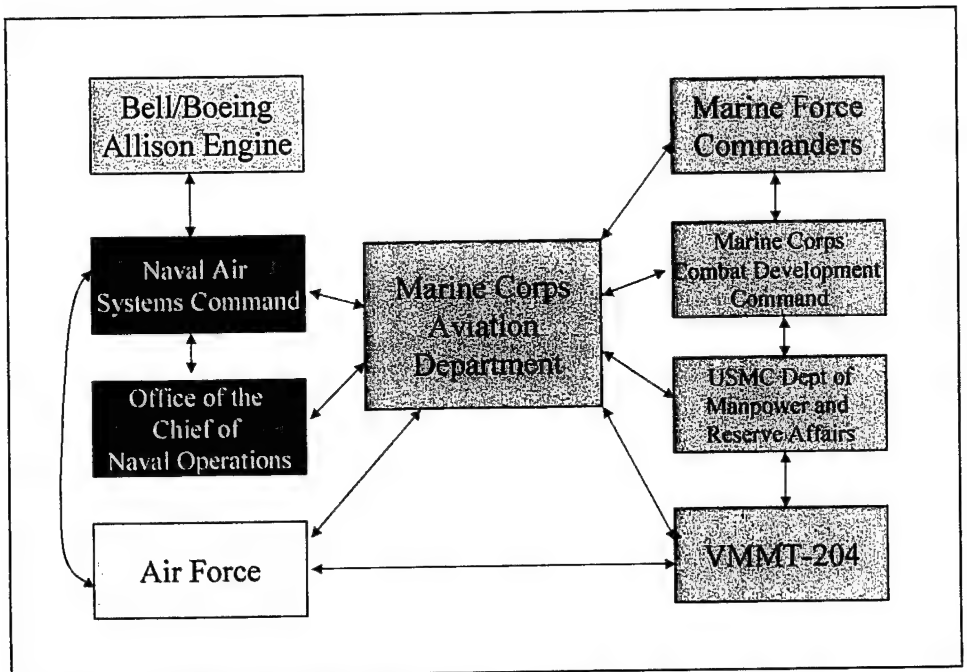

Figure 3. Key Players in the MV-22 Transition
[after MV-22, 1999]

With the Marine Corps Aviation Department as the focus, many agencies within and outside the Marine Corps must communicate their needs and coordinate their efforts throughout the V-22 transition. These agencies are responsible for all aspects of the transition plans and policies necessary to field the V-22 in the Department of Defense.

The Marine Corps Aviation Department, Marine Corps Combat Development Command, Marine Corps Department of Manpower and Reserve Affairs, and

VMMT-204, as a group, synchronize personnel training requirements with resource availability to meet the Marine Corps' needs and the needs of the other services. A change in the transition plan affects each agency and must be assessed for feasibility within each agency's functional area of responsibility.

C. TRANSITION GUIDANCE

In January 1999, the Marine Corps Aviation Department issued the mission order to "... organize, train, and equip (MV-22 forces) in order to field, deploy, and employ the MV-22 Osprey in a quick and efficient manner" [Gardner, 1999]. The mission intent is to achieve a dramatic and immediate impact on Marine Corps operations with MV-22 capabilities without reducing combat effectiveness of Marine units in the process of transitioning from the CH-46E and CH-53D. Additionally, the guidance states the transition should minimize the impact on existing deployment schedules, maintain unit cohesion, and ensure that, after the first MV-22 deployment on each coast, all subsequent deployments from that coast use MV-22s. Furthermore, time-to-train thresholds have been established for accomplishing individual and unit training goals [Gardner, 1999].

A five-phase course of action has been developed. (See Table 2.) The MV-22 transition is currently in the first of the five phases. Phase I, "Train the Trainers" (Oct 1998 - Mar 2001), prepares VMMT-204 for its instructional duties. Phase II (Mar 2001 - Oct 2004) requires transition of four East Coast CH-46E squadrons to Marine Medium Tilt-rotor Squadrons (VMMs) for subsequent inclusion in the overseas deployment cycle. Phase III (Apr 2004 - Oct 2007) transitions four West Coast CH-46E squadrons for inclusion in the West Coast deployment cycle. Phase IV (Jul 2006 -Feb 2008) transitions all CH-46E and CH-53D squadrons in Hawaii and Okinawa. Phase V (2008 - 2014) completes the transitions of the CH-46E squadrons remaining on the West and East Coasts, in that order, and includes them in their respective deployment cycles. [Gardner, 1999]

PHASE	TIME	OBJECTIVE
I – Train the Trainers	Oct 1998 – Mar 2001	Prepare VMMT-204 for Instructional Duties
II – East Coast Initial	Mar 2001 – Oct 2004	Transition East Coast CH-46E squadrons
III – West Coast Initial	Apr 2004 – Oct 2006	Transition West Coast CH-46E squadrons
IV – Hawaii and Okinawa	Jul 2006 – Feb 2008	Transition Hawaii and Okinawa CH-46E and CH-53D squadrons
V – Complete West and East Coasts	2008 – 2014	Transition remaining West Coast and East Coast CH-46E squadrons

Table 2. Phases of V-22 Transition

The Marine Corps plans to transition to the MV-22 in five phases. Transition begins with four East Coast CH-46E squadrons before heading west with four more CH-46E squadrons. Next, Okinawa and Hawaii transition, followed by the remainder of the West Coast, and finally the East Coast.

The Marine Corps has made every effort to incorporate lessons learned from previous aircraft transitions. In July 1988, while assigned to Officer Assignments Branch, Marine Corps Department of Manpower and Reserve Affairs, W. R. Jones wrote a Memorandum for the Record to "consolidate lessons learned for use during the MV-22 and later conversions" [Jones, 1988]. This memorandum is valued as the best "How To..." guidance for aircraft transition planners. Among other recommendations, Jones emphasizes the need to get all training resources (e.g., aircraft, simulators, and instructors) in place at the FRS well in advance of the first transition class. Jones encourages manpower planners to control entry into the V-22 community so as to achieve an equitable distribution of flight experience within each new V-22 squadron and also across the entire V-22 community. Additionally, Jones recommends establishing personnel rotation policies that keep pilots in fleet units during the early years of the transition in order to gain additional experience with the new aircraft, rather than assign them to non-flying billets. Well-planned rotation policies promote increased operational

proficiency while ensuring recent flight experience and knowledge is passed on to newly-trained V-22 pilots.

D. TRANSITION CONSIDERATIONS

In addition to the guidance described above, planners must attend to details. The following list, while not exhaustive, suggests the types of issues influencing FRS training plans:

- Transition plans must follow all training directives and policies;
- Transition plans must include post-FRS advanced tactical training;
- Transition plans must not adversely affect operational deployment cycles;
- Transition plans must incorporate personnel rotation policies that promote V-22 pilot population growth and ensure equitable distribution of rank and experience in transitioning units;
- Transition plans must be feasible with the training resources available; and
- Transition plans must incorporate lessons learned from the Naval Aviation Production Process Improvement Program.

The details of these considerations are discussed below.

1. Training Directives

Marine Corps Order P3500 Series, The Marine Corps Training and Readiness Manual, Volumes 1-8, (T&R1-T&R8) contains regulations and policy governing Marine Aviation Training. The T&R Manual defines the Marine Aviation Training and Readiness Program in its entirety. The purpose of the Marine Aviation Training and Readiness Program is to develop unit warfighting abilities based upon unit-level and individual *core competencies.* [T&R1, 1999; T&R8, 1999]

T&R1 outlines the overall philosophy of the T&R program and establishes unit-level core competencies for each aviation community. T&R1, Appendix A defines the requirements for a squadron in each aviation community. The requirements are the "core

competency" standard, defined as "the minimum level of performance a unit must be capable of sustaining during extended contingency/combat" [T&R1, 1999].

Aviation units are required to maintain core competency at all times. In order to achieve core competency, squadrons must meet standards for unit-level proficiency and individual pilot proficiency. T&R8 defines the training syllabi for achieving and maintaining individual pilot proficiency in basic flying skills, called "core skills." A minimum number of pilots must be qualified in each of the core skills for a squadron to be core competent. Furthermore, squadrons must maintain a base of experienced pilots qualified to instruct new pilots and also lead advanced tactical missions. Together, T&R1 and T&R8 establish the standards for individual core skills, flight leadership and instructor designations, and unit-level proficiency that define core competency standards. (See Table 3.)

CORE SKILL	# Required
Confined Area Landings	16
Formation Flight	16
External Lift Operations	16
Aerial Refueling	16
LDRSHIP/INSTR DESIGNATION	**# Required**
Aircraft Commander	12
Section Leader	6
Division Leader	4
Air Mission Commander	2
Night Systems Instructor	4

Table 3. Sample Core Competency Requirements

Each squadron must maintain a minimum number of pilots qualified in V-22 core skills. Additionally, each squadron must maintain a minimum number of pilots holding advanced flight leadership and instructor designations. [T&R8, 1999]

T&R8 contains the V-22 tilt-rotor training syllabi for FRS training and advanced tactical training. T&R8 lists one complete FRS syllabus for new pilots just out of flight school and constructs syllabi for experienced pilots using subsets of the complete syllabus. The FRS syllabi are sometimes called Category 1 through Category 5 (Cat1-Cat5), although T&R8 contains more descriptive terms, as indicated in Table 4.

Flight Syllabus Category	T&R8 Term	Type of Pilots Trained
Category 1 (Cat1)	Basic	new pilots just out of flight school
Category 2 (Cat2)	Transition	experienced pilots switching to the V-22 from another aircraft
Category 3 (Cat3)	Refresher	V-22 pilots who have not flown in the past 24 months
Category 4 (Cat4)	Modified Refresher	V-22 pilots whose last flight was more than 16 months but less than 24 months previous
Category 5 (Cat5)	Instructor Under Training	V-22 pilots training to become instructor pilots

Table 4. FRS Syllabi

T&R8 lists the training events required for each of five different FRS syllabi. The syllabi are designed to train pilots based on their overall flight experience and most recent flight experience. The syllabi follow the same overall structure, however the flight requirements decrease as student flight experience increases. [T&R8, 1999]

Each syllabus leads a student pilot through progressively more difficult stages of flight training while introducing core skills. (See Table 5.) Each stage consists of Interactive Media Instruction and independent study, simulator flights, and aircraft flights. Certain simulator and aircraft flights in each stage are flown at night, some with night vision goggles. Early stages of training are very regimented, however, later stages allow flexibility in scheduling.

Stage of V-22 FRS Training	Purpose
Interactive Media Instruction	Computer-based training to develop familiarization with aircraft systems and procedures
Familiarization	Develop familiarization with aircraft systems and basic maneuvers
Instruments	Develop familiarization with instrument flight and navigation
Confined Area Landings	Develop familiarization with landing in confined areas
Navigation	Develop familiarization with visual navigation
Tilt-rotor Low Altitude Tactics	Develop familiarization with low altitude flight maneuvers
Formation	Develop familiarization with formation flying
Externals	Develop familiarization with external transport of cargo
Combat Capable Check	Proficiency check in basic flight maneuvers and V-22 systems knowledge

Table 5. Stages of V-22 FRS Training

A V-22 FRS syllabus consists of progressively more difficult stages of training. The initial stages follow a regimented schedule, however later stages may be interchanged, or conducted concurrently, to make the best use of training opportunities.

After FRS training, pilots begin tactical flight training with their fleet units. Most advanced tactical training is described in T&R8 and may be conducted by fleet squadron instructors, however some training syllabi require certification from instructors from Marine Aviation Weapons and Tactics Squadron One (MAWTS-1). The MAWTS Course Catalog contains these syllabi [MAWTS, 2000]. Table 6 contains a sample of V-22 flight leadership and instructor designations. The syllabi requiring MAWTS certification are denoted with an asterisk; all others are listed in T&R8. T&R1, T&R8, and the MAWTS Course Catalog contain all the core competency requirements for a Marine MV-22 squadron.

Designation		#Req'd	Description
Section Leader		6	Permitted to lead missions involving two aircraft
Division Leader		4	Permitted to lead missions involving three or more aircraft
Flight Leader		2	Permitted to lead multi-division missions
Air Mission Commander		2	Permitted to lead entire missions involving multiple flights of varying aircraft in a complex tactical mission
Defensive Measures Instructor	*	2	Permitted to instruct initial training in defensive measures
Air Combat Maneuvering Instructor	*	2	Permitted to instruct initial training in air combat maneuvering
Night Systems Instructor	*	4	Permitted to instruct initial training in night flying involving night systems
Weapons and Tactics Instructor	*	1	Permitted to instruct all tactical training

Table 6. Sample MV-22 Flight Leadership and Instructor Designations

Pilots achieve graduate level designations by completing advanced training prescribed in either T&R8 or the MAWTS-1 Course Catalog. To be core competent, a squadron requires a minimum number of pilots holding these designations. With these designations, a squadron can conduct all the training necessary to maintain core competency.

2. Post-FRS Advanced Tilt-rotor Training

The Marine Corps has considered several alternatives for bringing CH-46E and CH-53D units through the V-22 transition to achieve core capability. The Marine Corps contracted SY Technology, Inc. of Arlington, Virginia, to conduct an end-to-end study of the V-22 transition plan to assess the proposed alternatives and make a recommendation for the best alternative [SY, 1999]. The study recommends the alternative that employs an Advanced Tilt-rotor Training Unit (ATTU) to conduct post-FRS training. Pilots from VMMT-204 would staff the ATTU and train fleet squadrons to initial core competency standards. After achieving core competency, a fleet squadron never returns to the ATTU for training.

3. Operational Deployment Cycles

Presently, Marine CH-46E squadrons are on a 30-month deployment cycle. The cycle begins with an 18-month period in which the squadron trains to core competency standards and prepares its personnel and aircraft for an overseas deployment. Six months prior to deployment, small detachments of heavy-lift CH-53E helicopters, light-attack UH-1 and AH-1 helicopters, and AV-8B jets join the squadron. The reinforced CH-46E squadron becomes the Air Combat Element of a Marine Expeditionary Unit (MEU). The MEU conducts six months of intensive pre-deployment training before departing for a pre-assigned theater of operations. After a six month deployment, the MEU, the reinforcing aircraft return to their original squadrons, and the CH-46E squadron recommences another cycle. (See Figure 4.)

The Marine Corps wants to incorporate MV-22 squadrons into the deployment cycle as soon as possible. However, doing so requires extensive coordination and planning to ensure a complete transition can be accomplished without disrupting the deployment cycle. Aviation Department guidance establishes a general blueprint for the transition, beginning with four East Coast squadrons before moving the transition focus to West Coast squadrons. This leaves four East Coast MV-22 squadrons to execute the deployments currently being completed by six CH-46E squadrons. The inter-deployment training period is reduced significantly, which demands efficient use of FRS and fleet unit training time and assets. This situation arises again during the West Coast transition. (See Figure 5.)

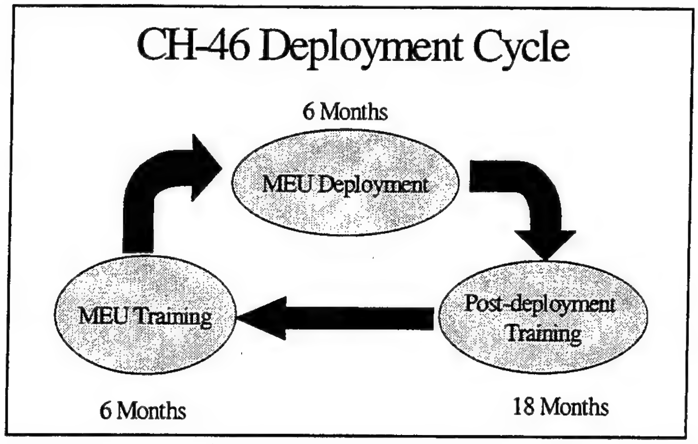

Figure 4. CH-46E Squadron Deployment Cycle

A Marine Corps CH-46E squadron deploys on a 30-month cycle. After joining a Marine Expeditionary Unit (MEU), a CH-46E squadron trains for six months prior to deploying overseas for six months. After returning from deployment, a CH-46E squadron replaces departing pilots and trains to maintain core competency standards. After 18 months, the squadron commences another cycle.

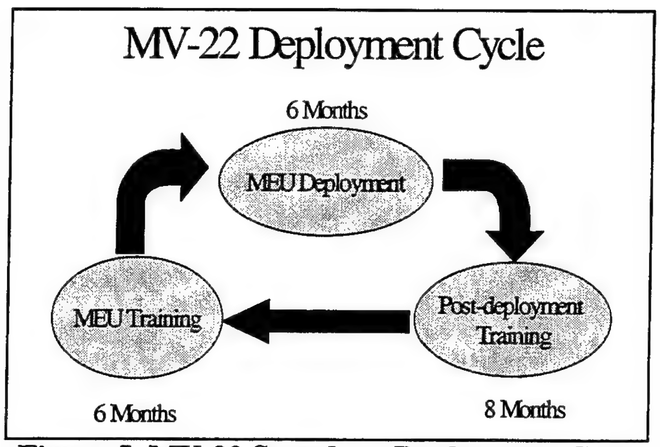

Figure 5. MV-22 Squadron Deployment Cycle

Initially, a Marine Corps MV-22 squadron will deploy on a 20-month cycle. Six months of pre-deployment training will precede a six-month deployment with a Marine Expeditionary Unit (MEU). After returning from deployment, a MV-22 squadron will replace departing pilots and train to maintain core competency standards. After eight months, the squadron will recommence another cycle.

4. Personnel Rotations and Bathtub Effect

After a CH-46E squadron returns from deployment, a number of pilots leave the squadron for various reasons. In the most severe circumstances, as much as half the squadron may leave in the months following a deployment. These pilots are replaced gradually during the 18-month period prior to pre-deployment training with the Marine Expeditionary Unit. This is known colloquially as the "Bathtub Effect." (See Figure 6.)

The Bathtub Effect has been permissible, although not ideal, for the 30-month CH-46E deployment cycle. However, given the demands on MV-22 units imposed by the shortened deployment schedule, the Bathtub Effect must be eliminated so MV-22 units may achieve stability in personnel and training prior to joining the Marine Expeditionary Unit. A moderate Bathtub Effect may be permissible in the later years of the transition as more squadrons enter deployment cycles, however planners are working to eliminate the Bathtub Effect entirely.

The FRS does not deploy, but it has rotational considerations of its own. Instructor pilots must rotate to other duties, too. For each instructor that rotates, a new one must be ready to replace him. This creates a large training burden in the early years of the transition as new instructors must first become qualified V-22 pilots before beginning the instructor syllabus. Personnel rotation policies must consider their impact on FRS training resources and the FRS instructor base.

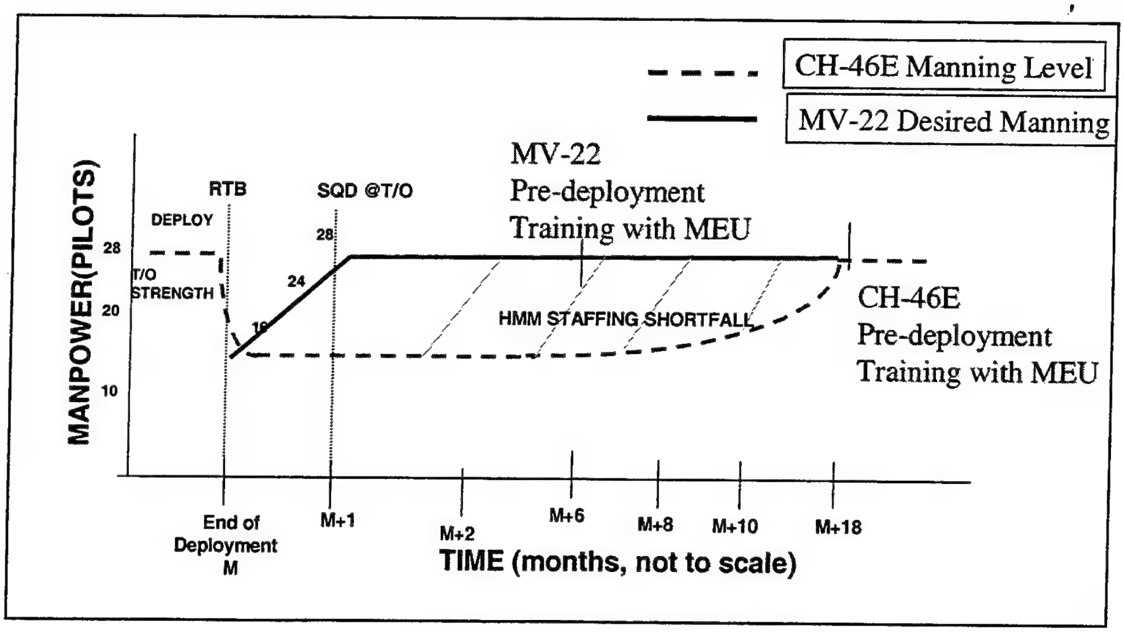

Figure 6. The Bathtub Effect
[after ASM, 2000a]

Marine CH-46E squadron manning levels typically follow the dashed line, giving rise to the term "Bathtub Effect". Notice the post-deployment reduction in manning and the gradual build-up to full manning levels just prior to pre-deployment training with the MEU. The shortened MV-22 deployment cycle requires elimination of the Bathtub Effect so that MV-22 squadrons may achieve stability in personnel and training prior to joining the MEU.

5. USMC and Air Force Manpower Requirements

In addition to concerns about the post-deployment Bathtub Effect, manpower planners must also ensure the V-22 pilot community grows in accordance with Marine Corps service-wide manpower plans. The Marine Corps expresses the desired fiscal year-end Military Occupational Specialty population with the term Grade Adjusted Recapitulation (GAR). Complex manpower models at Marine Corps Department of Manpower and Reserve Affairs determine GAR levels. The models consider accessions to the V-22 community and also losses due to pilot resignations and pilot retirements, among other factors. V-22 pilot training plans should support GAR goals for each fiscal year.

Pilot Training Requirement (PTR) is a term used to define annual pilot training quotas. It is sometimes used to define specific quotas for each FRS syllabus (e.g., 16

Pilot Training Requirement (PTR) is a term used to define annual pilot training quotas. It is sometimes used to define specific quotas for each FRS syllabus (e.g., 16 Cat1 pilots in FY 2001, 30 Cat2 pilots in FY 2001), but it is also used to define quotas for aggregate FRS production in a given year (e.g., 60 Cat1 *equivalent* pilots during FY 2001). To eliminate confusion, PTR will be used here strictly in the former sense, to designate the requirements for each FRS syllabus for the fiscal year. PTR can be considered to be the production blueprint necessary to achieve GAR, given the anticipated population losses.

Each year, Training and Education Division at Marine Corps Combat Development Command assigns PTR quotas to the FRS based upon manpower requirements and FRS training capabilities. The Air Force tells the Marine Corps Aviation Department its annual PTR, and the Marine Corps builds transition plans to satisfy both services' requirements. Whereas Marine Corps pilots will be trained in accordance with the unit transition schedule, Air Force pilots are spread uniformly throughout the year.

6. Availability of Training Resources

The principal FRS training resources affecting pilot training are aircraft flight hours, simulator hours, and instructor pilots. The V-22 Weapons System Planning Document is the procurement and delivery plan for V-22 aircraft, simulators, and support equipment [WSPD, 1999]. Aviation Department planners develop the planning document in concert with Bell/Boeing and Naval Air Systems Command counterparts. Transition planning tries to verify that there are sufficient training resources to support all training needs. However, weapons procurement plans are always subject to Congressional modification, so planners must incorporate flexibility into their transition plans. Similarly, new weapons systems are frequently subject to reduced utilization limits or delays in production schedules that result in reduced training capacity.

For these reasons, the Marine Corps bases training plans on reduced resource availability. The Training and Education Division at Marine Corps Combat Development Command assesses FRS training capacity using only 80% of available flight hours. The remaining 20% are allocated to the FRS for maintenance flights, instructor proficiency

flights, and as a reserve for possible surges in training requirements. This allows the FRS to adjust plans and priorities in the event of prolonged bad weather or maintenance delays. The FRS can adjust flight hours from month to month to meet training requirements, as necessary.

Simulator availability is more predictable. Civilian simulator instructors are under contract to provide 16 hours of instruction per day. The simulator itself is extremely reliable and requires some preventive maintenance outside of contracted training hours. However, the schedule for simulator usage is stipulated in the contract, so there is no opportunity to shift simulator hours from one month to the next in anticipation of increased simulator needs.

Each aircraft training flight requires an instructor pilot. The FRS is assigned a specific number of instructors in its Table of Organization. Each pilot is assigned a billet in the squadron in addition to his flight responsibilities. Typically, the squadron billet requires more time than instructional duties require. Additionally, safety conferences, ground training, temporary duty, and personal leave remove instructors from the flight schedule and decrease overall instructor availability. Instructor availability is as much a concern as aircraft and simulator availability.

7. Naval Aviation Production Process Improvement Program

In 1998, the Chief of Naval Aviation Training instituted the Naval Aviation Production Process Improvement Program. The goal of the program is to "... reduce time-to-train by up to 40% and sustain improvements... (and) ... produce more aviators in a shorter period of time and at a steady rate" [NAPPI, 2000]. The Navy has contracted the Thomas Group to assist, and the Thomas Group recommends eliminating "barriers" to efficiency that lead to excessive delays in training. These barriers may be in the form of excessive regulations, unnecessary training events, misguided policy, or resource utilization in excess of resource availability. Elimination of the barriers will lead to shorter time-to-train due to continuous training progression with fewer mid-training delays.

Implicit in barrier removal is the requirement for V-22 transition planners to ensure training schedules do not demand resource utilization in excess of resource

availability. Should resource requirements exceed availability, training will have to stop for some pilots until resources become available. The initiatives also emphasize continuous training progress once training begins. V-22 FRS planning must be based upon "just-in-time" principles that schedule pilots to begin training in anticipation of requirements and in compliance with resource availability constraints. Additionally, the flight school training command must provide students to begin FRS training in sufficient time to meet MV-22 unit core competency deadlines.

E. CURRENT PLANNING METHODS

A number of transition planning methods are already in use to address these considerations. Aggregate average assessment of FRS capacity is used, and Gantt charts are used to assess the feasibility of a single plan over time. Spreadsheets assess the impact of plans manually entered. None of these methods automatically prescribe or adjust training plans in light of manpower and operational needs and FRS resource availability.

T&R1 offers a formula that divides a percentage of total flight hours by the number of flight hours for the Cat1 syllabus to determine the PTR quotas for the year. This method was reasonable in the past when flight training was conducted primarily in the aircraft and simulator availability was rarely an issue. However, this planning method is less reliable for the V-22 transition because simulator usage exceeds aircraft usage in most of the FRS syllabi. Aggregate averaging is quick (e.g., one aircraft equates to 8.4 pilots trained per year), but fails to capture non-uniform resource requirements as one progresses through a syllabus.

SY Technology, Inc. used Microsoft Project© [MSFT, 2000a] Gantt charts and process timelines to analyze the proposed training plans. The analysis considers resource requirements in light of resource availability and presents a unit training template (with monthly fidelity) for transitioning units. The SY Technologies, Inc. study offers a unit transition template with ranges of class size and composition that are deemed feasible for initial transition. [SY, 1999]

The Aviation Department uses manual spreadsheet entry to construct FRS training schedules (with monthly fidelity) within the guidelines suggested by the SY study. Class composition (i.e., number of students in each syllabus) is determined by the Marine V-22 unit transition template described in the SY study. Air Force students are scheduled in sufficient quantities to meet quarterly and annual Air Force requirements. The spreadsheets provide no detailed information regarding resource utilization induced by the plan.

The Operations Department at VMMT-204 receives the proposed plans and conducts detailed analysis using flight schedules created by hand to assess their feasibility. With simplifying assumptions such as "16 simulator hours per day" and "17 flight hours per day," VMMT-204 Operations constructs possible flight schedules to determine if the plan from Headquarters can be accomplished. This is necessary to ensure T&R8 pre-requisites have not been "averaged out" in the creation of the overall plan. This method is labor-intensive and requires a good deal of time to address a four-month training plan. This method is unreasonable for developing a ten-year plan.

II. THESIS PURPOSE

The purpose of this thesis is to assist V-22 planners in developing FRS training plans in support of V-22 transition requirements. Current methods require planners to develop a training schedule first and then assess its impact on training resources. The methods are labor-intensive, time-intensive, and reliant on the experience of the planner for speed and accuracy. V-22 planners want a decision support tool that automatically creates a training schedule for achieving operational and manpower requirements without exceeding resource constraints.

The decision support tool should answer the following questions:

- Can USMC fleet squadrons transition to MV-22 core capability standards and achieve full T/O manning in the timetable prescribed?
- To what degree can the FRS handle transition requirements and post-deployment replenishment requirements simultaneously?
- Does the current plan support GAR and PTR goals?
- Are there enough training resources available to meet all the training needs? If yes, where does extra capacity exist? If no, where do current plans exceed capability?
- Is there enough capacity to support instructor training in addition to FRS student training?
- What resource utilization is induced by the current plan?
- What plan minimizes the impact of unachieved goals?

A decision support tool that helps answer these questions enables a more critical analysis of training plans for feasibility and optimality. An automated procedure that replaces manual planning methods could be of great benefit to transition planners.

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III. MODEL DEVELOPMENT

Standardized core competency requirements and standardized training syllabi suggest the use of *templates* for developing training plans. One creates a *syllabus template* by dividing the syllabus into a sequence of ordered *segments* and assigning resource usage (aircraft hours, simulator hours, and instructor training events) according to each segment's expected training.

One creates a *unit template* by dividing a unit into groups of pilots with similar flight qualifications. A training schedule is created by *sliding* syllabus templates along a time scale and *aligning* them to satisfy unit, operational, and manpower requirements without *overlapping* them to such a degree that FRS training capacity is exceeded.

A model based on the template concept permits finer resolution of training plans and prevents "averaging out" non-uniform resource usage as one progresses through a syllabus. The template analysis here uses a half-month time unit called a *period.* Time is measured in periods; two periods per month (e.g., period 1 is days 1-15, period 2 is days 16-31), 24 periods per year, and 240 periods over a ten-year planning horizon. A syllabus is divided into sequential segments that are also a half-month long. A student completes one segment of a syllabus in one period. The half-month fidelity captures sufficient detail of the syllabus without over-specifying the sequence of training events.

A. FRS SYLLABUS TEMPLATES

The Training Course Control Document (TCCD) for V-22 Pilot (100 Level) provides explicit training requirements for each day of the Cat1 syllabus [TCCD, 1999]. Poor flying weather and holidays preclude following the TCCD exactly. However, the TCCD is reasonable for outlining the progress of a student through the Cat1 Syllabus. By dividing the TCCD into half-month segments and recording the resource utilization for each segment, one creates the Cat1 template. While the TCCD is not published for all FRS syllabi, syllabus templates for the other FRS syllabi can be created using the TCCD and Cat1 template as a baseline. (See Appendix A.)

Figure 7 presents aircraft and simulator usage for each segment of the Cat1 syllabus template. The first four syllabus segments differ noticeably from the average resource utilization. Ignoring this can have dramatic effects on training plans. For instance, with 100 simulator hours per period, an average template with 7.2 simulator hours per segment suggests nearly 14 students could begin to train at once. The Cat1 template allows less than six to start at once, due to high simulator usage in segment three.

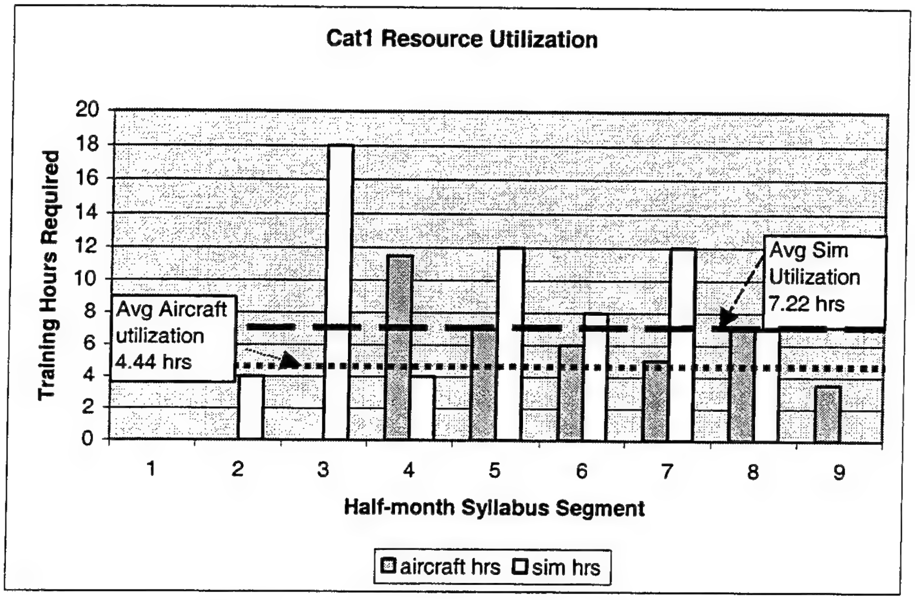

Figure 7. FRS Cat1 Syllabus Template

In the Cat1 syllabus, simulator training begins in the second period and peaks in the third period, whereas aircraft flight training begins and peaks in the fourth period. Utilization differs noticeably from the average utilization per segment.

B. UNIT TEMPLATES – COMPETENCY AND REPLENISHMENT

ATTU training is less regimented than FRS training, so FRS-style templates are not an accurate representation of the ATTU syllabi. Eleven designations are distributed among 16 pilots who must train at the ATTU, and the squadron commanding officer may distribute the designations in many different ways. Given this, resource utilization templates would be imprecise. However, ATTU time-to-train templates may be used to represent ATTU training and associate with each designation an expected time to achieve it. To simplify the ATTU designations, four groups (ATTU1 through ATTU4) are used

to represent collections of ATTU designations with similar time-to-train requirements. (See Appendix A.) Table 7 lists four simplified ATTU syllabi and their expected time to train.

	ATTU Syllabus Groups			
	attu1	attu2	attu3	attu4
Time-to-train (periods)	8	8	7	6

Table 7. ATTU Time-to-train Table

Syllabus groups ATTU1 through ATTU4 are assigned an expected time-to-train based upon the syllabus requirements for each group. Training for each of these syllabi must be started in sufficient time meet core competency target dates.

A squadron Table of Organization (T/O) requires 28 pilots. In addition to 16 pilots completing ATTU training, 12 more pilots must complete FRS training only. To create an equitable distribution of rank and flight experience, eight of the 12 must be new copilots and four must be pilots with previous fleet experience. For modeling purposes, these 12 pilots are called either "basic copilots" (bascop) or "experienced copilots" (expcop). Table 8 lists the required number of pilots for each unit to achieve core competency and have a full T/O.

Squadron	# ATTU Pilots Required				FRS Pilots Only	
T/O	ATTU1	ATTU2	ATTU3	ATTU4	expcop	bascop
28	2	2	8	4	4	8

Table 8. MV-22 Core Competency and T/O Requirements

MV-22 squadron T/O requires 28 pilots. Core competency standards require 16 pilots qualified in all the core skills and some with advanced designations received at the ATTU. The table lists the number of pilots required to complete each ATTU syllabus for the squadron to be core competent. (See Appendix A.) Of the remaining 12 pilots, eight must be basic copilots and four must be copilots with previous fleet experience.

Manpower planners have proposed typical post-deployment replenishment templates [MMOA, 2000; ASM, 2000b]. Each MV-22 squadron requires eight basic co-pilots and four experienced co-pilots during each post-deployment replenishment, as indicated in Table 9.

Syllabus Group	Group Description	# Pilots Required
Expcop	Copilots with previous Fleet experience	4
Bascop	Copilots without previous fleet experience	8
Squadron Total	**Post-deployment Replenishment Template**	**12**

Table 9. Post-deployment Replenishment Template for MV-22 squadron

Immediately after returning from deployment, MV-22 squadrons require new pilots to replace pilots who depart for follow-on assignments, resignation, or retirement, among other reasons. Manpower planners project that squadrons will require 12 new pilots after each deployment. Of these 12, four will be experienced pilots returning to the fleet and eight will be new pilots from flight school.

C. ALIGNING AND SLIDING TEMPLATES

For squadron pilots to complete ATTU training and to achieve core competency at the same time, FRS and ATTU templates must *align* as shown in Figure 8. FRS training must begin early enough to allow immediate follow-on ATTU training for core competency. Non-ATTU pilots begin FRS training after ATTU pilots, so the entire unit completes training together.

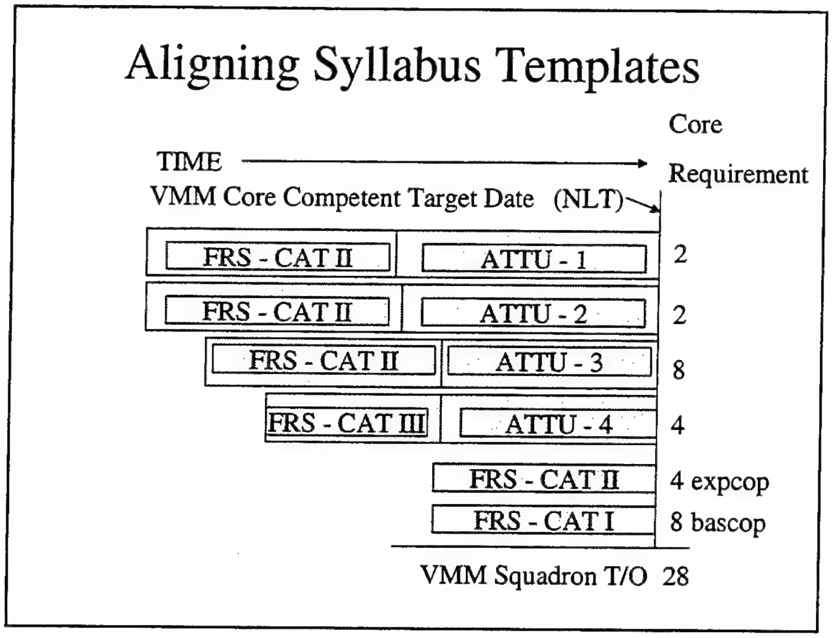

Figure 8. Aligning Syllabus Templates to Meet Unit Transition Requirements for Core Competency

In order to be core competent by the assigned deadline, a unit must begin training early enough to allow FRS training and ATTU training, if required. Different ATTU syllabi may combine with FRS syllabi to create a step-like template for a transitioning unit, with template ends aligning for synchronous syllabus completion.

Flexible plans may allow templates to *slide* so training is completed within a window of time. Refer to Figure 9 for a detailed example of sliding a Cat2 and ATTU1 template. Suppose an ATTU1 pilot is required during Period 29. If FRS Cat2 training lasts for 9 periods and ATTU1 training last for 8 periods, ATTU1 core competency requires 17 periods of training for a Cat2 pilot. The pilot must begin training at the beginning of Period 13 in order to complete training during Period 29. If it is acceptable for the pilot to complete training one period prior to the target period (i.e., Period 28), sliding the completion date transfers directly to the start and creates a window with two acceptable start periods: Periods 12 and 13.

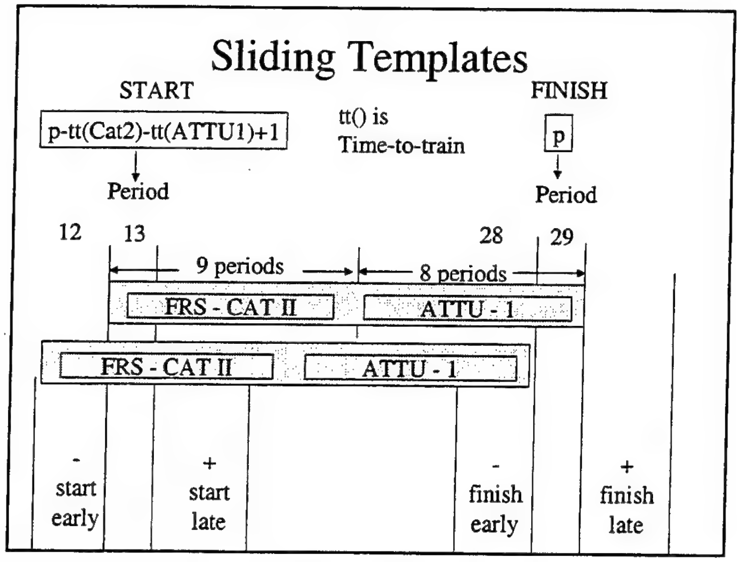

Figure 9. Sliding Cat2 and ATTU1 Templates so Training Completes within an Acceptable Completion Window

To complete ATTU1 training during Period p, a Cat2 FRS student must begin training during period *p-tt(Cat2)-tt(ATTU1)+1*. Early completion windows may be included in order to relax requirements, and these relaxations are transferred back in time to define a corresponding start window. If it is acceptable for this student to complete training during Periods 28 *or* 29, he may begin training at the beginning of either Period 12 or 13.

D. OVERLAPPING TEMPLATES - RESOURCE UTILIZATION

Several different FRS classes may train simultaneously, and each class induces different resource requirements based upon that class's current syllabus segment. The model must capture resource utilization caused by *overlapping* templates. Refer to Figure 10 for a hypothetical example of flight hour utilization and overlapping templates. During Quarter q, the Cat1 syllabus students who begin in Period p0 complete syllabus segments 3 through 8 of the 9-segment syllabus. The Cat3 students who begin in Period p1 complete segments 2 through 5 of the syllabus during Quarter q. Multiplying flight hour utilization for each segment by the number of students in each syllabus yields the flight hours scheduled for that syllabus segment and time period. Total flight hours scheduled during Quarter q is the sum of flight hours scheduled for both syllabi over the periods that define the quarter. Aircraft flight hours are allocated over quarters, while

simulator hours and instructor events are allocated over half-month periods, but the same logic applies to determine simulator and instructor utilization.

Aircraft Hours per Syllabus Segment

Syllabus	Segment → 1	2	3	4	5	6	7	8	9
Cat1	0	0	0	11.5	7	6	5	7	3.5
Cat3	0	6.5	10	8.5	3.5				

Aircraft Flight Hours Scheduled

# pilots	period → p0	p1	p2 (Quarter q)	p3 (Quarter q)	p4 (Quarter q)	p5 (Quarter q)	p6 (Quarter q)	p7 (Quarter q)	p8
5 Cat1	0	0	0	57.5	35	30	25	35	17.5
3 Cat3	NA	0	19.5	30	25.5	10.5	NA	NA	
Tot a/c hrs	0	0	19.5	87.5	60.5	40.5	25	35	17.5
						Quarterly Total Aircraft Hours		268	

Figure 10. Example of Overlapping Templates and Aircraft Flight Hour Utilization

The Cat1 syllabus lasts nine periods, and the Cat3 syllabus lasts five periods. Aircraft flight hour utilization during each segment of each of these two syllabus templates is presented in the top template. If these two candidate templates are scheduled such that five Cat1 pilots begin training in Period p0 and three Cat3 pilots begin training in Period p1, this induces flight hour usage as displayed in the lower half of the figure. Quarter q encompasses Periods p2 through p7. Summing the flight hours scheduled for each template and each segment in Quarter q yields 268 flight hours.

E. COMPETING GOALS – LIMITED RESOURCES – PENALTY LOGIC

Ideally, templates align in accordance with all planning goals and overlap without exceeding FRS resources. When this is not possible, a prioritization scheme is necessary to decide which template (i.e., pilot) to schedule given the limited resources remaining. The model does this by assessing a penalty for each pilot by which the model solution deviates from training goals. Penalties are discounted over time to prioritize imminent goals over future goals. An optimal model solution is the solution with the least total penalty. (Appendix B discusses the penalty scheme in detail.)

For instance, when confronted with a situation in which resources are available to train just one pilot, and demands exist for a Marine instructor pilot and a fleet pilot, the model should have clear guidance as to which pilot to schedule. To guide the model to prioritize the instructor over the fleet pilot, a greater penalty is assessed for instructor deficiencies than fleet pilot deficiencies. In seeking the optimal solution, the model will choose the schedule that accumulates the least overall penalty. Penalty logic is necessary

to adjudicate operational versus manpower conflicts, Marine versus Air Force conflicts, and core competency versus replenishment conflicts, to name a few. (See Table 10.)

Goal	Schedule Result	Penalty/ Pilot	Marine Corps Priorities (Descending Order)
Core Competency-Initial Transition	Late from ATTU	1	1) Instructor Pilots
	ATTU Deficiency	20	2) ATTU Pilots
	Experienced Copilot Deficiency	10	3) Basic Copilots for Initial Transition
	Basic Copilot Deficiency	15	4) Experienced Copilots for Initial Transition
Post-Deployment Replenishment	Experienced Copilot Deficiency	8	5) Basic Copilots for Replenishment
	Basic Copilot Deficiency	9	6) Experienced Copilots for Replenishment
Instructor Pilot Status at VMMT-204	Surplus	0.5	7) Discourage late ATTU completion
	Deficiency	25	8) Discourage Surplus of Instructors at FRS

Table 10. Sample Penalties and Supporting Logic

To prioritize pilots, the model assesses a weighted penalty for each pilot by which the model solution deviates from a desired goal. In the example above, the model prioritizes (with a higher deficiency penalty) instructor pilot requirements over ATTU core competency requirements. Similarly, training in support of core competency has higher priority than training for post-deployment replenishment. Surplus instructor training is penalized to discourage premature training in anticipation of future requirements.

IV. MODEL FORMULATION

The template approach to aircrew training may be expressed as a mathematical formulation. Fleet Replacement Aircrew Training Scheduler (FRATS) uses a four-dimensional variable *COHORT* to schedule FRS classes to meet operational goals and manpower goals without exceeding FRS resources (i.e., aircraft flight hours, simulator hours, and IP events). *COHORT* identifies the number of pilots trained and uses four indices to indicate the unit to which pilots are assigned, the FRS and ATTU syllabi (templates) required, and the time when pilots will begin training.

Section A introduces a simplified example formulation using just a two-dimensional *COHORT* to explain the model. In the simplified example, *COHORT* indices denote which of three training syllabi is scheduled and the time at which training begins. Only one unit and one operational deployment cycle are considered. This simplified formulation considers only aircraft flight hour utilization.

Section B contains the complete formulation, which addresses operational deployment cycles for all units, Air Force and Marine Corps manpower requirements, and all training resource utilization issues. The complete model uses elastic variables, integer and continuous variables, a four-dimensional *COHORT* indexing, and discounted penalties to capture the subtleties of V-22 transition planning requirements.

A. SIMPLIFIED EXAMPLE FORMULATION

1. Indices

f training syllabus {NOATTU, ATTU, IUT}.

p, px ordinal half-month period starting Oct 1, 2000 {1, 2, ..., 240}

(Oct 1 -15, 2000 is period 1, Oct 16-31 is period 2, etc.).

q ordinal fiscal quarter {1,2,..., 40}.

y, y' fiscal year {2001, 2002, ..., 2010}.

sf syllabus segment, ordinal half-month period in a syllabus $\{1, 2, \ldots, 10\}$.

2. Index Sets

compwin window in which pilots must complete core competency training for initial transition (set of period indices).

replwin window in which pilots must complete FRS training to replace pilots during post-deployment replenishment (set of period indices).

3. Data (units in parentheses)

$coreto_f$ number of pilots with qualifications from training syllabus f that are required for core competency. (pilots).

replpil number of *noattu* pilots required for post-deployment replenishment (pilots).

gar_y Grade Adjusted Recapitulation requirement for fiscal year y (pilots).

$ptr_{f,y}$ Pilot Training Requirement for syllabus f in fiscal year y (pilots).

$achrs_{f,sf}$ expected number of aircraft flight training hours required by each student in segment sf of FRS syllabus f (aircraft flight hours).

$tachrsavail_q$ aircraft flight hours allocated to ATTU and NOATTU FRS training in quarter q (aircraft flight hours).

$achrsavail_q$ total aircraft hours available for FRS training, including IUT flight hours, in quarter q (aircraft flight hours).

$ipgoal_p$ desired number of fully trained instructor pilots at VMMT-204 during period p (instructor pilots).

4. Variables

$COHORT_{f,p}$ integer variable; number of pilots beginning training in syllabus f at the beginning of period p (pilots).

$EXCESS_p$ positive variable; number of pilots that may begin the *noattu* syllabus at the beginning of period p (pilots).

5. Formulation

FRATS solves a sequence of two optimization models to produce each final training plan. The former fixes all $EXCESS_p$ variables equal to zero and then schedules $COHORTs$ to satisfy the constraints. The latter fixes the $COHORT$ variables at their optimal value from the first solution and then maximizes the number of $EXCESS$ pilots that can be scheduled with the remaining resources.

Formulation Objectives:

$$\underset{COHORT}{MINIMIZE} \quad 0 \qquad \text{(Objective1S)}$$

$$\underset{EXCESS}{MAXIMIZE} \quad \sum_{p} EXCESS_p \qquad \text{(Objective2S)}$$

Subject to:

$$\sum_{\substack{p \\ \text{appropriate for } f,\, compwin}} COHORT_{f,p} = coreto_f \quad , \quad \forall f \qquad \text{(1S)}$$

$$\sum_{\substack{p \\ \text{appropriate for } replwin}} COHORT_{noattu,p} = replpil \qquad \text{(2S)}$$

$$\sum_{f \neq IUT} \sum_{\substack{p \\ \text{appropriate for } f,y}} COHORT_{f,p} = gar_y, \quad \forall y \qquad \text{(3S)}$$

$$\sum_{\substack{p \\ \text{appropriate for } f,y}} COHORT_{f,p} = ptr_{f,y}, \qquad \forall f, y \tag{4S}$$

$$\sum_{\substack{p \\ \text{appropriate for } f,q,y}} COHORT_{f,p} \geq floor(ptr_{f,y}/4), \qquad \forall f, y, q \text{ in year } y \tag{5S}$$

$$\left[\begin{array}{l} \sum_{f \neq IUT} \sum_{\substack{sf,p \\ \text{appropriate for } f,\, q}} achrs_{f,sf} * COHORT_{f,p} + \\ \sum_{\substack{sf,p \\ \text{appropriate for } q}} achrs_{noattu,sf} * EXCESS_p \end{array} \right] \leq tachrsavail_q, \qquad \forall q \tag{6S}$$

$$\left[\begin{array}{l} \sum_{f} \sum_{\substack{sf,p \\ \text{appropriate for } f,\, q}} achrs_{f,sf} * COHORT_{f,p} + \\ \sum_{\substack{sf,p \\ \text{appropriate for } q}} achrs_{noattu,sf} * EXCESS_p \end{array} \right] \leq achrsavail_q, \qquad \forall q \tag{7S}$$

$$\sum_{\substack{px \\ \text{appropriate for } IUT,p}} COHORT_{IUT,px} = ipgoal_p, \qquad \forall p \tag{8S}$$

$$COHORT_{f,p} \geq 0, \quad \text{integer} \qquad \forall f, p \tag{9S}$$

$$0 \leq EXCESS_p \leq 6, \qquad \forall p \tag{10S}$$

6. Verbal Formulation of Simplified Example

The labeled model components express the following notions:

(Objectives): First, FRATS sets $EXCESS_p$ equal to zero and solves the model to ensure all constraints are satisfied for (Objective 1S). (The Simplified Example here assumes feasibility to simplify the formulation. The Complete Formulation in Section B addresses potential infeasibilities.) (Objective 2S) expresses the maximum number of $EXCESS$ pilots that can be trained in addition to the optimal $COHORT_{f,p}$ variables that were fixed at their optimal values from (Objective 1S).

Multiple optimal solutions may exist for (Objective1S). By fixing the $COHORT_{f,p}$ variables to the values of the first optimal solution, FRATS restricts the solution set for (Objective2S) and solves a relatively easy linear program. In doing so, FRATS achieves solutions quickly, however FRATS sacrifices the opportunity to find $COHORT_{f,p}$ and $EXCESS_p$ values that yield solutions to (Objective1S) that are no worse than the first solution (fixed by FRATS) and potentially better than the FRATS solution for (Objective2S).

(1S), (2S) Operational Goals: Sufficient number of pilots must begin training in syllabus f early enough to complete training in the competency window (Eq. 1S) and replenishment window (Eq. 2S) to meet operational requirements.

(3S)-(5S) Manpower Goals: At the end of each fiscal year y, the V-22 pilot population must equal the GAR goal (Eq. 3S). This is achieved by satisfying annual PTR goals (Eq. 4S) and spreading annual training equally among the four quarters of a fiscal year (Eq. 5S). *floor*() is the least integer less than or equal to the value in parentheses.

(6S), (7S) Resource Limitations: The number of aircraft flight hours scheduled for non-IUT flights during quarter q must not exceed the number of flight hours allocated for training (Eq. 6S). The number of aircraft flight hours scheduled for all flights during quarter q, including IUT flights, must not exceed the number of flight hours available (Eq. 7S).

(8S) FRS Manning: The number of pilots completing IUT training prior to period p must meet Instructor Pilot manning goals for period p.

(9S) $COHORT_{f,p}$ is a non-negative, integer variable, which represents the number of students who begin training in syllabus f at the beginning of period p.

(10S) $EXCESS_p$ is non-negative continuous variable to represent the number of students that may begin *NOATTU* training at the beginning period p. To spread out excess training, $EXCESS_p$ is restricted to values less than six, which prevents scheduling large quantities of notional excess training in a single period.

B. COMPLETE FORMULATION

1. Indices

a. Unit Indices

u — unit to which pilot is assigned {VMM-264, ..., VMM-263, VMMT-204, USMC Staff, AF}.

$\tilde{u}$ — USMC units, subset of u {VMM-264, ..., VMM-263, VMMT-204, USMC Staff}.

$\hat{u}$ — USMC Fleet units, subset of u {VMM-264, ..., VMM-263}.

b. Syllabus Indices

s — pilot training syllabus {cat1, …, cat4, cat5a, cat5b, attu1,…, attu4, expcop, bascop}.

f — FRS syllabus, subset of s {cat1, …, cat4, cat5a, cat5b}.

$\hat{f}$ — subset of f comprised of {cat1, …, cat4}.

$\tilde{f}$ — subset of f comprised of {cat2, cat3, cat4}.

$\bar{f}$ — subset of f comprised of {cat1, cat2, cat5a}.

f' — subset of f comprised of {cat1, cat2}.

iut — FRS Instructor Under Training syllabi, subset of f comprised of {cat5a, cat5b}.

$refs$ — FRS refresher syllabi, subset of f comprised of {cat3, cat4}.

a — ATTU syllabus, subset of s {attu1, attu2, attu3, attu4, expcop, bascop}.

a' — nominal ATTU copilot syllabus requiring no ATTU training, subset of a, comprised of {expcop, bascop}.

c. *Time Indices*

p, px period ordinal for a half-month length of time {1,2, ..., 240}. Period 1 begins 1 Oct 2000. Period 2 begins 16 Oct 2000.

q fiscal quarter ordinal {1,2, ..., 40} with quarter 1 beginning Oct 1, 2000.

y, yx fiscal year {2001,2002, ..., 2010}.

sf ordinal FRS syllabus segment (a segment lasts one half-month, the same length as period p) {1,2,...,10}.

$repl$ ordinal post-deployment pilot replenishment {1,2, ...,5}.

2. Index Maps

$\underline{p}(q), \overline{p}(q)$ first, last periods in quarter q.

$\underline{p}(y), \overline{p}(y)$ first, last periods in fiscal year y.

3. Index Sets

$qtrs(y)$ quarters q that occur during fiscal year y.

$t(u, f, a, p)$ permissible instances of unit u, FRS syllabus f, ATTU syllabus a, and period p.

$attuswin_{\hat{u},\hat{f},a}$ set of permissible periods during which pilots from unit $\hat{u}$ may start FRS training in syllabus f for subsequent ATTU training in syllabus a in order to meet squadron core competency to_a requirements.

$replswin_{\hat{u},\hat{f},repl}$ set of permissible periods during which pilots from unit $\hat{u}$ may start FRS training in syllabus f in order to meet pilot requirements for post-deployment replenishment $repl$.

4. Data (units in parentheses)

a. Marine Corps Operational Requirements Data

$coreto_a$ number of pilots with designations received at completion of FRS training and subsequent training in ATTU syllabus a that are required for VMM core competency (pilots).

$replpil_{a'}$ number of replacement pilots completing FRS training for nominal ATTU copilot syllabus a' required for each post-deployment replenishment (pilots).

b. Training Goals and Manpower Data

gar_y USMC Grade Adjusted Recapitulation requirement for fiscal year y (pilots).

$mcptr_{\hat{f},y}$ Marine Corps pilot training goal for FRS syllabus $\hat{f}$ for the end of fiscal year y (pilots).

$cummcloss_y$ cumulative number of V-22 pilots anticipated to leave the Marine Corps prior to the end of fiscal year y (pilots).

$ureflim_{refs,y}$ maximum number of Marine Corps pilots that are allowed to complete FRS refresher syllabus $refs$ during fiscal year y (pilots).

$afptr_{f',y}$ Air Force pilot training goal for FRS syllabus f' for the end of fiscal year y (pilots).

c. FRS Data

histtrnd number of fully-trained V-22 pilots at the beginning of period 1 (pilots).

histdprt number of fully-trained V-22 pilots who are not assigned to VMMT-204 at the start of period 1 (pilots).

$mcfrsip_p$ desired number of Marine Corps instructors assigned to VMMT-204 for FRS duty during period p (pilots).

$affrsip_p$ number of Air Force instuctors assigned to VMMT-204 for FRS duty during period p (pilots).

$attuip_p$ number of Marine Corps instructors assigned to VMMT-204 for ATTU duty during period p (pilots).

$cmcipdprt_p$ cumulative number of Marine Corps instructors expected to depart VMMT-204 in the time periods up to and including period p (pilots).

$actothrs_q$ total VMMT-204 aircraft flight hours allocated for FRS flight training, including instructor training, during quarter q (aircraft flight hours).

$simtothrs_p$ total simulator hours allocated for FRS training, including instructor training, during period p (simulator hours).

$actrnhrs_q$ aircraft flight hours allocated for student (i.e., Cat1 – Cat4) training during quarter q (aircraft flight hours).

$simtrnhrs_p$ simulator hours allocated for student (i.e., Cat1 – Cat4) training during period p (simulator hours).

ipevts expected number of events an instructor is available to fly during any given period (events).

d. Training Syllabus Data

tt_s expected time required to complete syllabus s (periods).

$achrs_{f,sf}$ expected number of aircraft hours required by each student in segment *sf* of syllabus f (aircraft flight hours).

$simhrs_{f,sf}$ expected number of simulator training hours required by each student in segment *sf* of syllabus f (simulator hours).

$evtsreq_{f,sf}$ expected number of training events utilizing an IP required by each student in segment *sf* of syllabus f (events).

e. Penalties

$penalties_p$ Penalty coefficients are assigned to each elastic variable. Different penalty weights are used to prioritize goals in the event resource requirements exceed resource availability. Penalties are discounted each fiscal year to motivate priority scheduling for near-term requirements. (See Appendix B.) (penalty/pilot).

$excwt_p$ Pilot training that is scheduled in excess of requirements is assigned a positive weight that is discounted each year to prioritize near-term scheduling (penalty/pilot).

5. Variables

$COHORT_{u,f,a,p}$ positive variable, integer for $p \leq 120$, continuous for $p > 120$; number of pilots from unit u who begin training training in FRS syllabus f at the beginning of period p for subsequent training in ATTU syllabus a. $COHORT_{u,f,a,p}$ completes FRS training during period $p + tt_f - 1$ and completes ATTU training in period $p + tt_f + tt_a - 1$.

$EXCESS_p$ positive continuous variable; number of pilots that may begin FRS Cat1 syllabus during period p.

$ELASTICVARIABLES_p$ positive continuous variables to satisfy constraints, as necessary. (See Appendix B.)

6. Formulation

FRATS solves a sequence of two optimization models to produce each final training plan. The former fixes all $EXCESS_p$ variables equal to zero and then schedules $COHORTs$ and $ELASTICVARIABLES$ to satisfy the constraints and incur the minimum cumulative penalty. The latter fixes the $COHORT$ variables and $ELASTICVARIABLES$ at their optimal value from the first solution and then maximizes the number of $EXCESS$ pilots that can be scheduled with the remaining resources.

$\triangleq$	indicates slack variables may be used to achieve equality (i.e., EXPRESSION+DEFICIT = LIMIT)
$\doteq$	indicates elastic variables may be used to achieve equality (i.e., EXPRESSION + DEFICIT − SURPLUS = LIMIT)
$\overline{\geq}$	indicates slack variables may be used to achieve inequality (i.e., EXPRESSION + DEFICIT ≥ LIMIT)

Formulation Objectives:

$$\underset{COHORT}{MINIMIZE} \quad \sum_{p} penalties_p * ELASTICVARIABLES_p \qquad \text{(Objective1C)}$$

$$\underset{EXCESS}{MAXIMIZE} \quad \sum_{p} excwt_p * EXCESS_p \qquad \text{(Objective2C)}$$

Subject to:

$$\sum_{\substack{(\hat{f},p) \text{ such that} \\ p \in attuswin_{\hat{u},\hat{f},a} \text{ and} \\ (\hat{f},p) \in t(\hat{u},\hat{f},a,p)}} COHORT_{\hat{u},\hat{f},a,p} \triangleq coreto_a \quad , \qquad \forall a,\hat{u} \qquad \text{(1C)}$$

$$\sum_{p \in replswin_{\hat{u},a',repl}} \quad \sum_{\hat{f} \in t(\hat{u},\hat{f},a',p)} COHORT_{\hat{u},\hat{f},a',p} \triangleq replpil_{a'} \quad , \quad \forall \hat{u},a',repl \qquad \text{(2C)}$$

$$\left[\begin{array}{l}\displaystyle\sum_{\substack{(\bar{f},p)\text{ such that}\\ p\le\bar{p}(y)-tt_{\bar{f}}+1}}\ \sum_{(\tilde{u},a)\in t(\tilde{u},\bar{f},a,p)} COHORT_{\tilde{u},\bar{f},a,p}\\ +histtrnd-cummcloss_y\end{array}\right] \doteq gar_y \qquad \forall y \tag{3C}$$

$$\sum_{p=\underline{p}(y)-tt_{\hat{f}}+1}^{p=\overline{p}(y)-tt_{\hat{f}}+1}\ \sum_{(\tilde{u},a)\in t(\tilde{u},\hat{f},a,p)} COHORT_{\tilde{u},\hat{f},a,p} \doteq mcptr_{\hat{f},y} \quad , \qquad \forall\hat{f},y \tag{4C}$$

$$\sum_{p\le\overline{p}(y)-tt_{f'}+1}\ \sum_{a'\in t(AF,f',a',p)} COHORT_{AF,f',a',p} \doteq \sum_{yx\le y} afptr_{f',yx} \quad , \qquad \forall f',y \tag{5C}$$

$$\sum_{p=\underline{p}(y)-tt_{f'}+1}^{p=\overline{p}(y)-tt_{f'}+1}\ \sum_{a'\in t(AF,f',a',p)} COHORT_{AF,f',a',p} \doteq afptr_{f',y} \quad , \qquad \forall f',y \tag{6C}$$

$$\sum_{p=\underline{p}(q)-tt_{f'}+1}^{p=\overline{p}(q)-tt_{f'}+1}\ \sum_{a'\in t(AF,f',a',p)} COHORT_{AF,f',a',p} \stackrel{\geq}{=} \text{floor}(afptr_{f',y}/4) \ \ , \ \ \forall f',y,q\in qtrs(y) \tag{7C}$$

$$\left[\begin{array}{l}\displaystyle\sum_{p=\underline{p}(q)}^{p=\overline{p}(q)}\ \sum_{\substack{(u,\hat{f},a,px)\text{ such that}\\ (u,\hat{f},a,px)\in t(u,\hat{f},a,px)\text{ and}\\ (\underline{p}(q)-tt_{\hat{f}}+1)\le px\le\overline{p}(q)}} achrs_{\hat{f},p-px+1} * COHORT_{u,\hat{f},a,px}\\ \displaystyle+\sum_{p=\underline{p}(q)}^{p=\overline{p}(q)}\ \sum_{px=\underline{p}(q)-tt_{cat1}+1}^{px=\overline{p}(q)} achrs_{cat1,p-px+1} * EXCESS_{px}\end{array}\right] \le actrnhrs_q,\ \forall q \tag{8C}$$

$$\left[\begin{array}{l} \displaystyle\sum_{\substack{(u,\hat{f},a,px) \text{ such that} \\ (u,\hat{f},a,px)\in t(u,\hat{f},a,px) \text{ and} \\ (p-tt_{\hat{f}}+1)\le px\le p}} simhrs_{\hat{f},p-px+1} * COHORT_{u,\hat{f},a,px} \\ \displaystyle + \sum_{px=p-tt_{cat1}+1}^{px=p} simhrs_{cat1,p-px+1} * EXCESS_{px} \end{array}\right] \le simtrnhrs_p \ , \qquad \forall p \qquad (9C)$$

$$\left[\begin{array}{l} \displaystyle\sum_{\substack{(u,f,a,px) \text{ such that} \\ (u,f,a,px)\in t(u,f,a,px) \text{ and} \\ (p-tt_f+1)\le px\le p}} evtsreq_{f,p-px+1} * COHORT_{u,f,a,px} \\ \displaystyle + \sum_{px=p-tt_{cat1}+1}^{px=p} evtsreq_{cat1,p-px+1} * EXCESS_{px} \end{array}\right] \le$$

$$ipevts * \left[\begin{array}{l} \displaystyle\sum_{iut} \sum_{px\le p-tt_{iut}} COHORT_{vmmt204,iut,expcop,px} \\ +affrsip_p + histtrnd \\ -histdprt - cmcipdprt_p - attuip_p \end{array}\right], \quad \forall p \qquad (10C)$$

$$\left[\begin{array}{l} \displaystyle\sum_{p=\underline{p}(q)}^{p=\overline{p}(q)} \sum_{\substack{(u,f,a,px) \text{ such that} \\ (u,f,a,px)\in t(u,f,a,px) \text{ and} \\ (\underline{p}(q)-tt_f+1)\le px\le \overline{p}(q)}} achrs_{f,p-px+1} * COHORT_{u,f,a,px} \\ \displaystyle + \sum_{p=\underline{p}(q)}^{p=\overline{p}(q)} \sum_{px=\underline{p}(q)-tt_{cat1}+1}^{px=\overline{p}(q)} achrs_{cat1,p-px+1} * EXCESS_{px} \end{array}\right] \le actothrs_q, \quad \forall q \qquad (11C)$$

$$\left[\begin{array}{l} \displaystyle\sum_{\substack{(u,f,a,px) \text{ such that} \\ (u,f,a,px)\in t(u,f,a,px) \text{ and} \\ (p-tt_f+1)\le px\le p}} simhrs_{f,p-px+1} * COHORT_{u,f,a,px} \\ \displaystyle + \sum_{px=p-tt_{cat1}+1}^{px=p} simhrs_{cat1,p-px+1} * EXCESS_{px} \end{array}\right] \le simtothrs_p \ , \qquad \forall p \qquad (12C)$$

$$\left[\begin{array}{l}\sum_{iut}\ \sum_{px\le p-tt_{iut}} COHORT_{vmmt204,iut,expcop,px} \\ +histtrnd \\ -histdprt - cmcipdprt_p \\ \end{array}\right] \doteq mcfrsip_p + attuip_p, \qquad \forall p \qquad (13C)$$

$$\sum_{p=\underline{p}(y)-tt_{refs}+1}^{p=\overline{p}(y)-tt_{refs}+1}\ \sum_{(\tilde{u},a)\in t(\tilde{u},refs,a,p)} COHORT_{\tilde{u},refs,a,p} \le ureflim_{refs,y} \quad , \quad \forall y, refs \qquad (14C)$$

$$COHORT_{u,f,a,p} \ge 0 \ , \ \text{ integer } \quad \forall u, f, a, p \le 120 \qquad (15C)$$

$$COHORT_{u,f,a,p} \ge 0 \ , \qquad \forall u, f, a, p > 120 \qquad (16C)$$

$$0 \le EXCESS_p \le 6 \ , \qquad \forall p \qquad (17C)$$

7. Verbal Formulation

The labeled model components express the following notions:

(Objectives) (Objective1C) expresses weighted penalties for failure to achieve pilot training goals. FRATS sets $EXCESS_p$ equal to zero and minimizes the total weighted penalties. In (Objective2C), FRATS sets all decision variables (i.e., $COHORT_{u,f,a,p}$ and *ELASTICVARIABLES)* equal to their optimal values from (Objective 1C), and maximizes the number of $EXCESS_p$ pilots that can be with remaining resources.

Multiple optimal solutions may exist for (Objective1C). By fixing *ELASTICVARIABLES* and $COHORT_{u,f,a,p}$ variables to the values of the first optimal solution, FRATS restricts the solution set for (Objective2C) and solves a relatively easy linear program. In doing so, FRATS achieves solutions quickly, however FRATS sacrifices the opportunity to find $COHORT_{u,f,a,p}$ and $EXCESS_p$ values that yield

solutions to (Objective1C) that are no worse than the first solution (fixed by FRATS) and potentially better than the FRATS solution for (Objective2C).

(1C) Pilots from unit $\hat{u}$ must begin training in FRS syllabus $\hat{f}$ early enough to complete ATTU syllabus a and meet $coreto_a$ goals during the competency window.

(2C) Pilots from unit $\hat{u}$ must begin training in FRS syllabus $\hat{f}$ early enough to complete nominal ATTU copilot syllabus a' and meet $repl_{a'}$ goals for post-deployment replenishment $repl$.

(3C) The total Marine Corps V-22 pilot population at the end of fiscal year y must meet USMC GAR goals.

(4C) The number of Marine Corps V-22 pilots completing training in FRS syllabus f' during fiscal year y must meet USMC PTR goals.

(5C) The cumulative number of Air Force V-22 pilots who have completed training in FRS syllabus f' up to and including the last period of fiscal year y must meet Air Force cumulative pilot training goals.

(6C) The number of Air Force V-22 pilots completing FRS syllabus f' during fiscal year y must meet Air Force PTR goals.

(7C) The number of Air Force V-22 pilots completing FRS syllabus f' during fiscal year y must be evenly distributed to each fiscal quarter q.

(8C)-(9C) FRS resource (i.e., aircraft flight hours, simulator hour) utilization induced by pilot *COHORT* training in FRS syllabi $\hat{f}$ and $EXCESS_p$ scheduling must not exceed resource allocations for training.

(10C)-(12C) FRS resource (i.e., aircraft flight hours, simulator hour, and instructor training events) utilization induced by pilot *COHORT* training and *EXCESS* scheduling must not exceed resource availability.

(13C) The number of trained Marine instructor pilots on hand at VMMT-204 during period p must equal Marine instructor manning goals for period p.

(14C) The total number of Marine Corps V-22 pilots completing FRS refresher training *refs* during fiscal year y must not exceed fiscal year refresher syllabus limits.

(15C)-(16C) $COHORT_{u,f,a,p}$ is a non-negative variable, integer in the first five years of the planning horizon, continuous afterwards.

(17C) $EXCESS_p$ is non-negative continuous variable to represent the number of Cat1 students that may commence training in period p. To spread out excess training, $EXCESS_p$ is restricted to values less than six, which prevents scheduling large quantities of excess capacity to begin in a single period.

C. DATA IMPLEMENTATION AND DATA SOURCES

1. Operational Requirements Data

$coreto_a$: T&R1 and T&R8 core competency requirements help derive $coreto_a$. (See Appendix A.) [T&R1, 1999; T&R8, 1999; VMMT-204, 2000]

$replpil_{a'}$: Officer Assignments Branch, Department of Manpower and Reserve Affairs provides expected replacement pilot requirements for post-deployment replenishment periods. [MMOA, 2000]

$attuswin(\hat{u}, \hat{f}, a)$: Marine Corps Aviation Department determines the core competency window for each unit $\hat{u}$. Based on that window, FRATS calculates an appropriate start window for pilots to begin training in FRS syllabus $\hat{f}$ for subsequent training in ATTU syllabus a. [APP, 2000]

$replswin(\hat{u}, \hat{f}, repl)$: Marine Corps Aviation Department determines the post-deployment replenishment window for each unit $\hat{u}$. FRATS calculates an appropriate start window for pilots to begin training in FRS syllabus $\hat{f}$ for replenishment ordinal $repl$. [APP, 2000]

2. Training Goals and Manpower Data

gar_y: Marine Corps Department of Manpower and Reserve Affairs computes GAR. FRATS models GAR for FY 2001 – FY 2006. [MPP, 2000]

$mcptr_{f',y}$: Training and Education Division at Marine Corps Combat Development Command determines appropriate PTR requirements for each fiscal year. [T&E, 2000]

$cummcloss_y$: Marine Corps Department of Manpower and Reserve Affairs forecasts pilot population losses when computing GAR. FRATS calculates $cummcloss_y$ from this data. [MPP, 2000]

$ureflim_{refs,y}$: Marine Corps Aviation Department, Marine Corps Department of Manpower and Reserve Affairs, and Aviation Training Branch at Marine Corps Combat Development Command provide data for approximating refresher syllabus training limits throughout the planning horizon. [ASM, 2000b; MMOA, 2000; T&E, 2000]

$afptr_{f',y}$: Air Force provides Marine Corps Aviation Department its training requirements for incorporation into transition plans. FRATS calculates cumulative goals and quarterly goals from $afptr_{f',y}$. [ASM, 2000b]

3. FRS Data

$histtrnd, histdprt$: At the start of the planning horizon (1 Oct 2000), FRATS must account for those pilots previously trained and those who were trained but do not serve at VMMT-204. VMMT-204 provides this data for FRATS. [VMMT-204, 2000]

$mcfrsip_p$: As the V-22 population grows, VMMT-204 will require more instructors. The Aviation Department and the Department of Manpower and Reserve Affairs determine projected FRS manning levels. [ASM, 2000b; MMOA, 2000]

$affrsip_p$: Air Force determines the appropriate number of Air Force instructors required throughout the planning horizon and sends its requirements to the Marine Corps Aviation Department and VMMT-204. [ASM, 2000; VMMT-204, 2000]

$attuip_p$: VMMT-204 determines ATTU manning levels throughout the planning horizon. [VMMT-204, 2000]

$cmcipdprt_p$: Marine Corps Department of Manpower and Reserve Affairs determines instructor rotation policies and plans. FRATS calculates $cmcipdprt_p$ from these plans. [MMOA, 2000]

$actrnhrs_q, actothrs_q$: The Marine Corps Aviation Department and Naval Air Systems Command determine how many aircraft to allocate to VMMT-204. A percentage (typically 80%) of total aircraft flight hours is allocated for student training (i.e., Cat1-Cat4). FRATS calculates $actrnhrs_q$ and $actothrs_q$ based upon aircraft allocations, estimates of flights hours per aircraft per month from the Weapons System Planning Document, training allocation percentages from Training and Education Division at Marine Corps Combat Development Command, and VMMT-204 estimates of an appropriate maintenance allocation percentage.
[APP, 2000; VMMT-204, 2000; WSPD, 1999; T&E, 2000]

$simtrnhrs_p, simtothrs_p$: The Marine Corps Aviation Department and Naval Air Systems Command determine how many simulators to allocate to VMMT-204. VMMT-204 allocates a percentage (typically 90%) of simulator hours for student training (i.e. Cat1-Cat4). FRATS calculates $simtrnhrs_p$ and $simtothrs_p$ based upon simulator allocations, civilian simulator instructor contractual agreements, and training allocation percentage.
[VMMT-204, 2000; APP, 2000]

$ipevts$: VMMT-204 determines the number of events an instructor may instruct per half-month. [VMMT-204, 2000]

4. Training Syllabus Data

tt_s: V-22 Training Course Control Document provides expected time-to-train for the Cat1 syllabus. Analysis conducted with VMMT-204 determines time-to-train for other syllabi as defined in T&R1 and T&R8. (See Appendix A.)

[TCCD, 1999; VMMT-204, 2000]

$achrs_{f,sf}$, $simhrs_{f,sf}$, $evtsreq_{f,fs}$: Training Course Control Document describes a syllabus template for Cat1 training. Analysis conducted with VMMT-204 determines resource utilization templates for the other syllabi. (See Appendix A.) [TCCD, 1999; VMMT-204, 2000]

5. Penalty Data

$penalties_p$: Penalties are determined using prioritization guidance from Marine Corps Aviation Department. Penalties are discounted 5% annually. (See Appendix B.) [APP, 2000; ASM, 2000b]

$excwt_p$: Excess pilot production is rewarded in the second solving routine of the model. The reward per excess pilot is discounted annually. (See Appendix B.)

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V. RESULTS

A. MODEL IMPLEMENTATION

FRATS is implemented in General Algebraic Modeling System (GAMS) (Release 2.5) [GAMS, 1998] using the CPLEX 6.6 solver [ILOG, 2000], and Microsoft Excel© [MSFT, 2000b] spreadsheets. FRATS uses a GAMS-Excel interface designed by Maliyev and Rutherford at the University of Colorado, Boulder [Maliyev and Rutherford, 1999] to import data and export the model solution to Excel spreadsheets. *The output Excel file may also be used without GAMS for manual planning.*

1. GAMS-Excel Interface

Model users are likely to be familiar with Excel, so the GAMS-Excel interface makes FRATS more user-friendly. FRATS requires input data to be entered into five pre-formatted spreadsheets contained in a single workbook file: an Operational Data spreadsheet, a FRS Data spreadsheet, a Syllabus Data spreadsheet, a Manpower Data spreadsheet, and a Penalty spreadsheet. (See Appendix C.) The optimal training schedule from GAMS is sent to a pre-formatted table the Master Schedule (Grand Plan) spreadsheet in the same Excel file. Resource utilization is calculated in Excel based on the entries in the table.

The FRATS output file reports overall goal achievement, the complete ten-year FRS schedule, ten-year FRS resource utilization, excess capacity, and unit-by-unit training schedules with half-month fidelity. (See Appendix D.) The output spreadsheets may also be used to display and evaluate a manual plan. Additionally, the user may change certain input data (e.g., aircraft allocations, syllabus templates, training allocations) and assess the resource utilization induced by the *existing* plan already entered in the pre-formatted table.

To run FRATS using GAMS, the GAMS-Excel interface program must be installed in the GAMS library on the computer running the model. Also, the interface requires exact cell references in the GAMS code, so the format of the spreadsheets must

not be altered. Once these administrative matters are addressed, the interface creates a user-friendly environment for data entry and documentation of model results.

2. GAMS Implementation

Using a baseline scenario over a ten-year planning horizon with half-month resolution, GAMS generates 1,276 equations, 3,991 variables, and 97,306 non-zero elements. The relative integrality tolerance is 5%, and the resulting the gap is 4.9%. FRATS finds a solution after 1,805 iterations in four minutes using a Pentium III, 1GHz personal computer with 1 Gigabyte of random access memory. Including the time required for the Excel interface, FRATS finds a solution and displays the results in about 10 minutes.

B. BASELINE SCENARIO RESULTS

The baseline scenario addresses fiscal years 2001 through 2010 (i.e., Oct 1, 2000 to Sep 31, 2010). The figures in Appendix C summarize the baseline scenario derived from data supplied by the Marine Corps Aviation Department, Department of Manpower and Reserve Affairs, Marine Corps Combat Development Command, and VMMT-204.

Priorities to resolve conflicts come from the Aviation Department. FRATS assesses FRS training capacity by using high penalty weights for scheduling deficiencies and modest penalty weights for scheduling surpluses. With these relative weights of penalties, FRATS schedules pilots for training in support of operational needs even if this training exceeds annual training goals. Conversely, if annual manpower goals have a deficit after operational goals are met, FRATS schedules pilots for training and subsequent assignment to *USMC Staff* in order to meet annual goals. In this manner, FRATS helps assess FRS training capacity while exposing disparities, intentional or otherwise, between operational and manpower goals.

The *deviations* and *deficiencies* of the optimal training schedule reflect policies and priorities (i.e., penalty weights) described by the input data. Different priorities may result in different deviations and deficiencies, *even if all other baseline input data remain the same*. Policy restrictions (e.g., narrower pilot delivery windows) may confine

FRATS decision variables to such a degree that significant deviations are unavoidable. FRATS enables objective assessment of different policies and priorities via the resultant deviations and deficiencies they induce in the optimal schedule.

The following sections frequently use the phrase "FRATS schedules deficiencies in…" to describe deviations that result in the optimal schedule. For the sake of brevity, this phrase replaces "The optimal FRATS schedule meets most operational and manpower goals, but found the following goals unattainable: …" FRATS does not create deficiencies; FRATS highlights unattainable goals given the input data and priorities.

1. Operational Goals

The baseline FRATS schedule identifies operational deficiencies in FY 2004-2005 and also FY 2008. (See Table 11.) During FY 2005, VMM-W1 and VMM-W2 (the first and second West Coast squadrons to transition) have deficiencies in experienced copilots during initial transitions, and several East Coast squadrons (VMM-264, VMM-266, and VMM-261) have experienced copilot deficiencies during post-deployment replenishments. VMM-261 and VMM-W4 have replenishment deficiencies in FY 2008.

Transition Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Experienced Copilots				* 3	* 4	
Basic Copilots						
Replenishment Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Replenishment 1 - expcop		* 4	* 4			2.83
Replenishment 1 - bascop		* 1				
Replenishment 2 - expcop	* 4					
Replenishment 3 - expcop			3.24			

Table 11. Operational Deficiencies of USMC Fleet Squadrons - Baseline Scenario

In the table above, the column labels list the USMC V-22 fleet squadrons and the row labels list the pilot deficiencies from the optimal FRATS schedule. The lower section contains replenishment deficiencies, with row labels for the ordinal replenishment and type of pilot for which the deficiency exists. Asterisks denote deficiencies that occur during FY 2005. For example, VMM-261 has a deficiency of four experienced copilots during its first post-deployment replenishment in FY 2005.

2. Manpower Goals

FRATS schedules Air Force pilots to meet annual Air Force goals in every year except FY 2010, when FRATS falls short by four pilots. The baseline FRATS schedule deviates from Marine manpower goals in several areas. Most notably, FRATS deviates from Grade Adjusted Recapitulation (GAR) goals in FY 2001 - FY2006. (See Figure 11.) The FRATS schedule in FY 2001 trains nine fewer pilots than the GAR goal. After FY 2001, the FRATS schedule exceeds GAR goals. This reflects the priorities of the baseline penalty scheme: FRATS schedules pilot training to meet operational needs, even if this exceeds manpower goals.

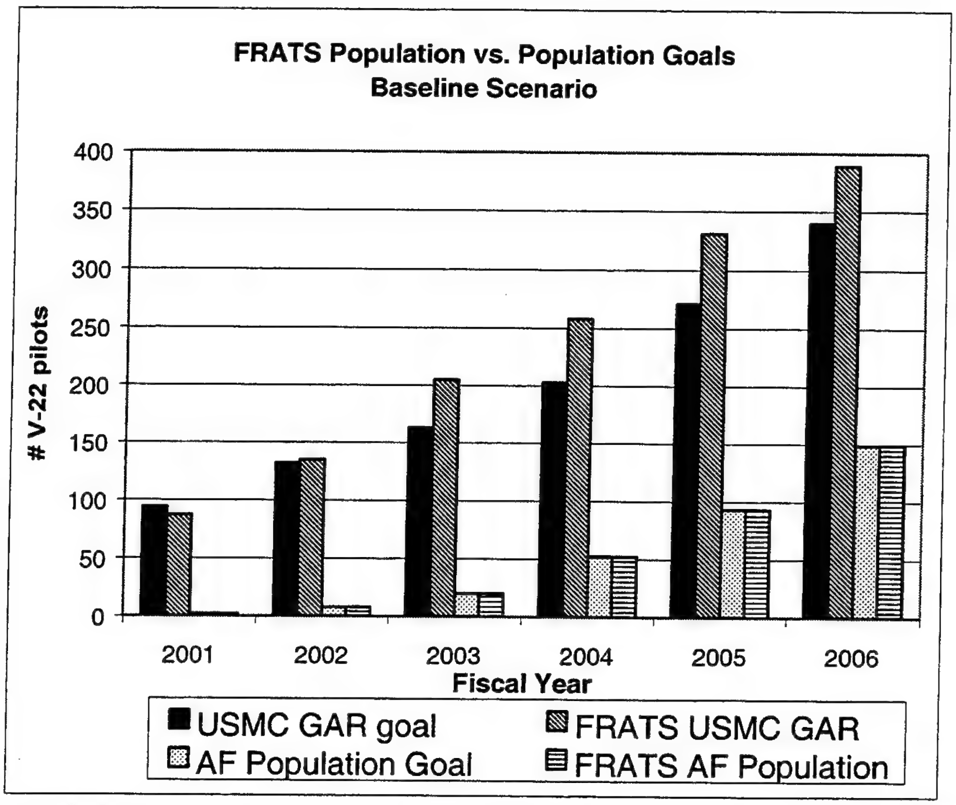

Figure 11. Pilot Population Goals versus FRATS Schedule – Baseline Scenario

The vertical axis is the cumulative number of V-22 pilots trained prior to the end of the fiscal year. The horizontal axis contains the first six years of the ten-year planning horizon. FRATS schedules Air Force pilots to meet Air Force goals during each of the first six years of the transition. The FRATS USMC schedule in FY 2001 falls nine pilots short of USMC GAR goals. In subsequent years, FRATS schedules exceed GAR goals.

3. Resource Utilization

Of the three resources, aircraft flight hours have the highest utilization percentage (i.e., number of hours scheduled divided by total hours available) over the ten-year planning horizon. (See Figure 12.) In every year except FY 2002, the percentage of total aircraft hours scheduled by FRATS exceeds the percentages scheduled for simulators and instructors. The highest aircraft hour utilization occurs in FY 2005, when 85% of available aircraft hours are scheduled.

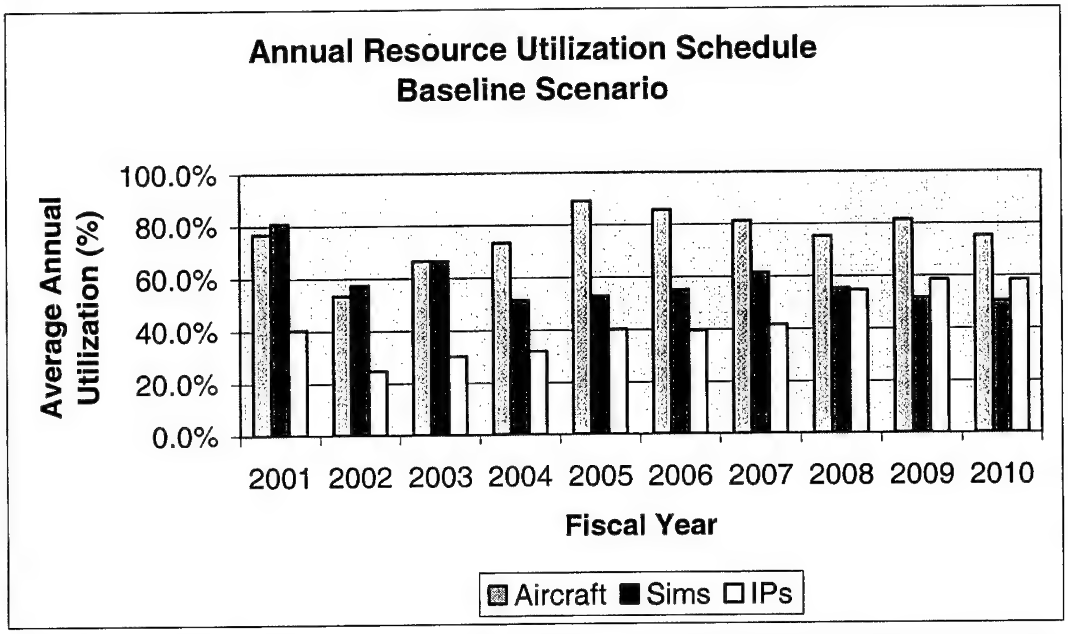

Figure 12. Average Annual Resource Utilization Scheduled by FRATS in the Baseline Scenario

For each fiscal year, FRATS calculates the average resource utilization. The average annual utilization is the total number of resource units (i.e., aircraft flight hours, simulator hours, and instructor events) divided by the total number of units available for the year. The vertical axis is the utilization percentage. The horizontal axis is the fiscal years in the planning horizon. In FY 2005, aircraft hours are scheduled at nearly 95% utilization, simulators are scheduled at 50% utilization, and instructors at 40% utilization. Aircraft utilization rates are highest every year except FY 2002, when simulator utilization is marginally higher.

The simulator and aircraft utilization in FY 2001 is near 80%. Although resource hours remain unscheduled for FY 2001, they are not sufficient to train another pilot. Figure 13 shows that simulator hours are scheduled at near 100% utilization in

November, February, March, May, and June of FY 2001. It is not possible to schedule another Cat1 or Cat2 syllabus without exceeding simulator usage in those periods.

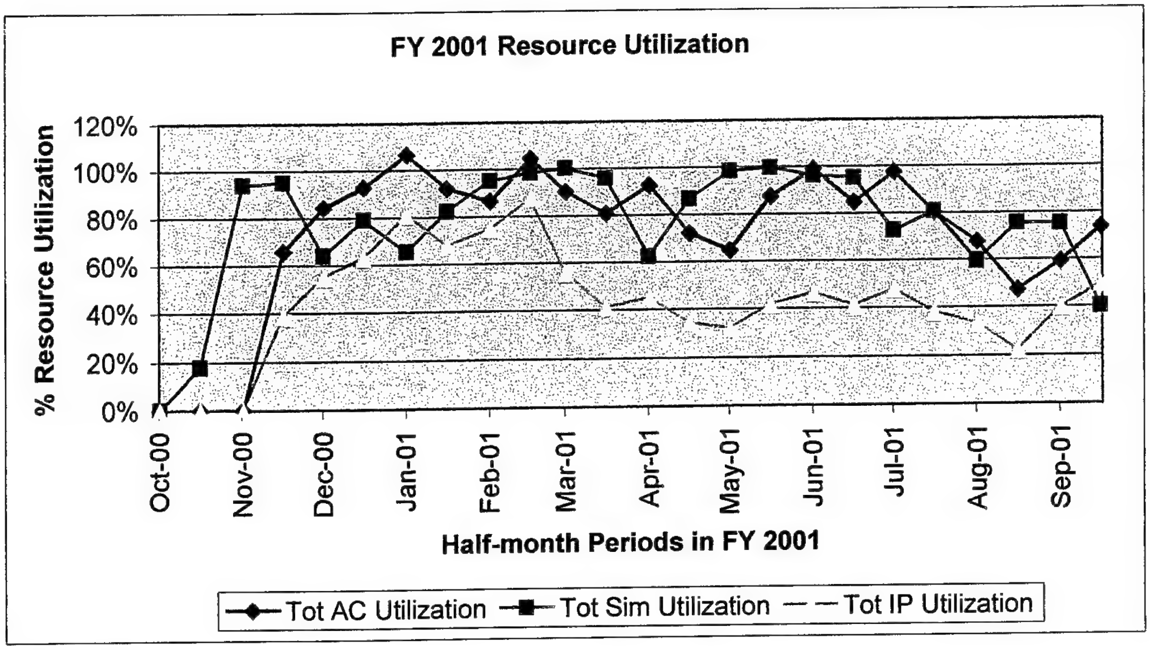

Figure 13. FRATS Schedule FY 2001 Resource Utilization – Baseline Scenario

The vertical axis is the resource utilization rate. The horizontal axis contains the half-month periods in FY 2001. The FY 2001 training schedule uses aircraft hours (dark diamonds) and simulator hours (squares) near their maximum capability. Aircraft hour utilization exceeds 100% in Jan FY 2001, which is permitted because aircraft hours are budgeted quarterly. Instructor event utilization (light triangles) exceeds 80% capacity only in Feb-Mar 2001. Simulator usage approaches 100% several times in FY 2001.

4. Insights on Marine Corps Duty Rotations

After a pilot's first tour in the fleet, Marine Corps Department of Manpower and Reserve Affairs assigns him a new billet based upon the needs of the Marine Corps, his personal desires, his previous assignments, and his professional development needs. In the MV-22 community, some USMC Staff pilots will rotate directly to Fleet units without further FRS training. Others will return to the FRS for refresher training in two to five years. Neither detailed MV-22 pilot rotation models n*or guidance* have been available during FRATS development.

FRATS models personnel rotations implicitly through experienced copilot requirements in core competency and replenishment templates, annual Cat3 and Cat4 Pilot Training Requirements, and limitations on Cat3 and Cat4 training each year. The templates identify pilots that require FRS training. Users may model anticipated Staff-to-Fleet rotations and Instructor-to-Fleet rotations by reducing the number of experienced copilots required by the unit templates, *thereby implicitly modeling a Staff-to-Fleet pilot who does not require FRS training.*

Where FRATS Grade Adjusted Recapitulation (GAR) exceeds GAR goals, the FRATS schedule suggests duty rotations are necessary to meet operational needs, *not* more new V-22 pilots just completing FRS training. Similarly, where FRATS identifies personnel deficiencies, rotation policies may be necessary, rather than additional training resources. Planners can, and should, deviate from the FRATS schedule where duty rotations lessen the FRS resource requirements and harmonize operational manning requirements with manpower goals.

5. FRS Instructor Pilot Manning

Due to a mishap in April 2000 that delayed aircraft delivery to VMMT-204, FRS instructor training has not progressed as anticipated. In the solution for the baseline scenario, FRATS shows how VMMT-204 can sequence new instructors into training without exceeding training resources and still have enough instructors and aircraft to begin training VMM-264 in April 2001. (See Figure 14.)

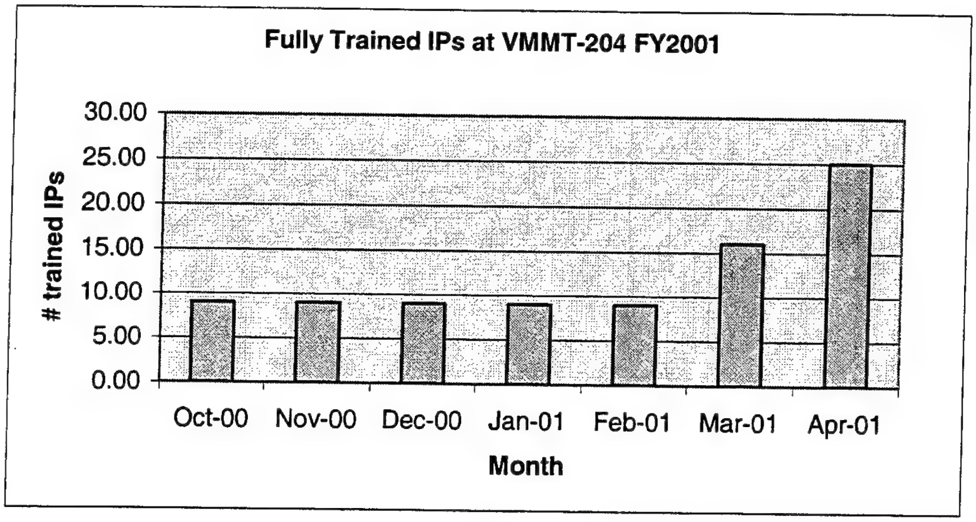

Figure 14. FRS IP Levels During FY 2001 – Baseline Scenario

The vertical axis is the number of fully trained FRS Instructor Pilots (IPs) at VMMT-204. The horizontal scale contains the first seven months of FY 2001. VMMT-204 begins the fiscal year with nine fully trained instructors, 16 short of the goal of 25. The first class of instructors completes training in March 2001 to increase the instructor ranks to 16. VMMT-204 has 25 fully trained instructors at the end of April 2001. The first class of fleet pilots arrives in March 2001 and requires flight instructors at the end of April.

C. EXCURSIONS

FRATS is useful for analyzing a variety of scenarios and the impact of policy changes. A few possible scenario variations are discussed below. Each scenario is considered independent of the others and imposes a single variation on the baseline scenario.

1. Augment FRS Aircraft with Fleet Aircraft

The Marine Corps Aviation Department has considered augmenting FRS aircraft with Fleet aircraft as transitioning units undergo FRS training [APP, 2000]. If a transitioning unit is still in FRS training when its aircraft arrive from the manufacturer, VMMT-204 may conduct acceptance inspections and use the aircraft for FRS training until the unit begins ATTU training. The increased number of aircraft may help to reduce operational deficiencies. (See Figure 15.)

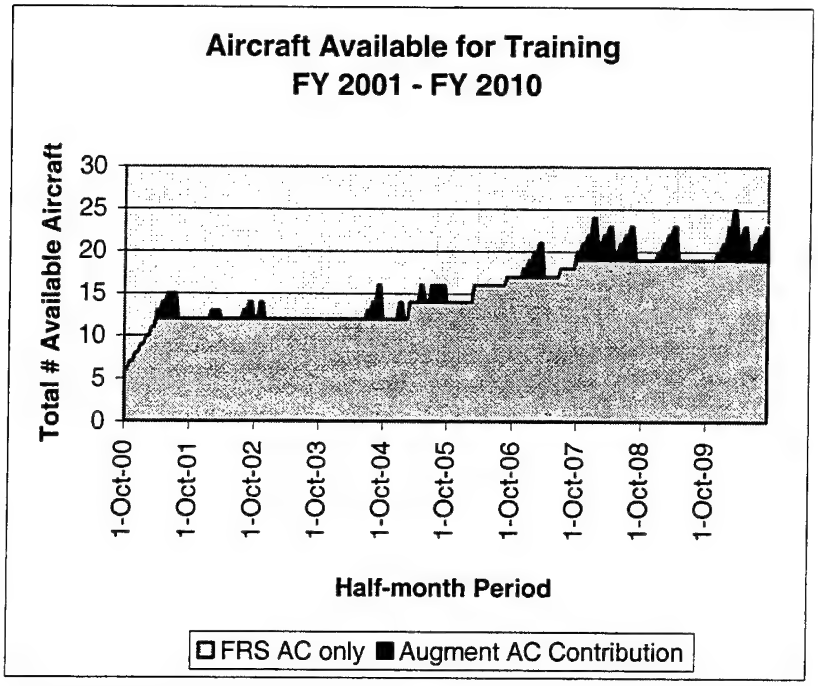

Figure 15. Aircraft Available for Training at the FRS -Augment Aircraft Scenario

The vertical axis is the total number of aircraft available for FRS training. The horizontal scale contains the half-month periods in FY 2001 – FY 2010. The total number of VMMT-204 aircraft is indicated in the lighter portion. The dark spikes are the augment aircraft added to the VMMT-204 aircraft. In March-June 2001, augment aircraft are added to the to increase the total number of aircraft from 12 to 15. In late FY 2001, the FRS has only 12 aircraft on its flight line again.

Table 12 indicates that the augment aircraft do not create a dramatic impact. VMM-W1 is able to train one more basic copilot for initial transition in January 2005, but this comes at the expense of a basic copilot for replenishment for VMM-266 in October 2004 (FY 2005). VMM-W4 and VMM-261 have fewer deficiencies during post-deployment replenishments, but these improvements are offset by an increase in VMM-261 deficiencies during its post-deployment replenishment in FY 2008. The augment aircraft will reduce the aircraft utilization rate and provide more flexibility when scheduling aircraft, but the additional flight hours will not be enough to eliminate many of the baseline deficiencies.

Transition Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Experienced Copilots				* -1		
Basic Copilots						
Replenishment Deficiencies	**VMM264**	**VMM266**	**VMM261**	**VMMW1**	**VMMW2**	**VMMW4**
Replenishment 1 - expcop						-1.33
Replenishment 1 - bascop		* +1				
Replenishment 2 - expcop						
Replenishment 3 - expcop		+ 4	- 3.24			

Table 12. Changes in Operational Deficiencies of USMC Fleet Squadrons – Augment Aircraft Scenario

In Table 12, the column labels list USMC fleet squadrons and the row labels list the operational deficiencies of the FRATS schedule. The upper section of the table contains transition deficiencies, with row labels for the type of pilot for which the deficiency exists. The lower section contains replenishment deficiencies, with row labels for the ordinal replenishment and type of pilot for which the deficiency exists. Asterisks denote deficiencies that occur during FY 2005. The values in the table indicate the change in the number of pilot deficiencies for each squadron and operational deficiency that existed in the baseline scenario. With fleet aircraft augmenting VMMT-204 aircraft, VMM-W1 is deficient one fewer experienced copilot during its initial transition in FY 2005. VMM-266 is deficient four additional experienced copilots during post-deployment replenishment in FY 2008.

2. Increase Aircraft Allocation for Training by 5%

In the baseline model, student training (i.e., Cat1 through Cat4) is limited to 80% of total aircraft hours available during a calendar quarter. VMMT-204 reserves the remaining 20% for instructor training or maintenance flights. With higher allocations for student training, it may be possible to train more pilots.

With 85% allocation, FRATS reduces the FY 2005 deficiencies, but not entirely. (See Table 13.) VMM-W2 eliminates its deficiency in experienced copilots during initial transition, although VMM-W1 increases its experienced copilot deficiency during initial transition by one pilot. VMM-266 also eliminates its basic copilot deficiency for replenishment in FY 2005. All FY 2008 deficiencies are eliminated.

Transition Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Experienced Copilots (expcop)				* +1	* -4	
Basic Copilots (bascop)						
Replenishment Deficiencies	**VMM264**	**VMM266**	**VMM261**	**VMMW1**	**VMMW2**	**VMMW4**
Replenishment 1 - expcop						-2.83
Replenishment 1 - bascop		* -1				
Replenishment 2 - expcop						
Replenishment 3 - expcop			-3.24			

Table 13. Changes in Operational Deficiencies of USMC Fleet Squadrons with 85% Training Allocation Scenario

With 85% of all aircraft hours allocated for training, many, but not all, of the deficiencies are reduced in FY 2005. All of the deficiencies in FY 2008 are eliminated. Experienced copilot requirements, the lowest priority, remain unfilled for FY 2005 post-deployment replenishments.

3. Widen the Delivery Window from 6 Weeks to 8 Weeks

FRATS schedules pilots for training based upon acceptable delivery windows. The baseline scenario has a three-period delivery window: one primary delivery period, one period prior, and one period after. Small delivery windows induce small start windows. Relaxing the delivery window to include two 2-week periods just before and one 2-week period just after the primary delivery period gives FRATS more scheduling flexibility. With a wider delivery window, FRATS reduces FY 2005 deficiencies by five pilots (four experienced copilots for VMM-W2's transition and one basic copilot for VMM-266's replenishment). FRATS shifts FY 2008 deficiencies between squadrons, but the wider delivery windows have minimal effect overall in FY 2008. (See Table 14.)

Transition Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Experienced Copilots					* -4	
Basic Copilots						
Replenishment Deficiencies	**VMM264**	**VMM266**	**VMM261**	**VMMW1**	**VMMW2**	**VMMW4**
Replenishment 1 - expcop						-2.83
Replenishment 1 - bascop		* -1				
Replenishment 2 - expcop						
Replenishment 3 - expcop		+4	-1.3			

Table 14. Changes in Operational Deficiencies of USMC Fleet Squadrons- 8-Week Delivery Window Scenario

With one 2-week period added to the beginning of the baseline delivery window, FRATS has more options for scheduling FRS classes. FRATS reduces FY 2005 deficiencies by five pilots (four experienced copilots and one basic copilot). FY 2008 has no real improvement; FRATS shifts deficiencies from VMM-W4 and VMM-261 to VMM-266.

4. Combined Excursions

With all three of the previous modifications incorporated into a single scenario, FRATS reduces most FY 2005 deficiencies and eliminates all FY 2008 deficiencies. (See Tables 15 and 16). A combination of these three slight modifications to the baseline scenario enables FRATS to reduce operational deficiencies over the ten-year planning horizon to six in FY 2005. It is reasonable to expect Staff-to-Fleet and/or FRS-to-Fleet rotations to fill these deficiencies.

Transition Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Experienced Copilots				* -3	* -3	
Basic Copilots						
Replenishment Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Replenishment 1 - expcop		* -3				-2.83
Replenishment 1 - bascop		* -1				
Replenishment 2 - expcop	* -4					
Replenishment 3 - expcop			-3.24			

Table 15. Changes in Deficiencies of USMC Fleet Squadrons- Augment Added to FRS Aircraft, 85% Aircraft Training Allocation, and 8-Week Delivery Window

By augmenting FRS aircraft with fleet aircraft during each squadron transition, increasing training allocation to 85%, and widening delivery windows to eight weeks, FRATS reduces the FY 2005 deficiencies by 14 pilots. The relaxed conditions allow FRATS to reduce FY 2008 deficiencies by six pilots. These three modifications combine to yield a dramatic improvement over the results of any single modification to the baseline scenario.

Transition Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Experienced Copilots					* 1	
Basic Copilots						
Replenishment Deficiencies	VMM264	VMM266	VMM261	VMMW1	VMMW2	VMMW4
Replenishment 1 - expcop		* 1	* 4			
Replenishment 1 - bascop						
Replenishment 2 - expcop						
Replenishment 3 - expcop						

Table 16. Deficiencies of USMC Fleet Squadrons- Augment Aircraft Added to FRS Aircraft, 85% Aircraft Training Allocation, and 8-Week Delivery Window

By augmenting FRS aircraft with fleet aircraft during each squadron transition, increasing training allocation to 85%, and widening delivery windows to eight weeks, FRATS reduces the FY 2005 deficiencies to six pilots: one experienced copilot for VMM-W2 transition, one experienced copilot for VMM-266 replenishment, and four experienced copilot for VMM-261. FY 2008 deficiencies are entirely eliminated.

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VI. CONCLUSIONS

FRATS indicates that the FRS lacks sufficient resources to meet operational needs during FY 2005 and, to a lesser degree, FY 2008, unless effective personnel rotations are incorporated into the transition plan. Augment aircraft, widened delivery windows, and increased aircraft training allocations would help reduce the deficiencies in FY 2005, but not eliminate them altogether. A personnel rotation plan that includes Staff-to-Fleet and FRS-to-Fleet assignments will reduce the training requirements for VMMT-204 and provide fleet units with qualified pilots.

In general, aircraft hours are the most limiting resource during the transition, followed by simulator time. If there are any increased training requirements or syllabus changes, these must be closely examined for their impact on aircraft utilization.

FRATS adapts easily to other Marine Corps aircraft transitions. Each Marine Corps aircraft transition will have a squadron core competency template that requires completion of training syllabi by a certain deadline. The training syllabi will induce resource utilization based on the sequencing and quantity of training required. Personnel must be scheduled to begin training in sufficient time to meet operational deadlines and manpower goals without exceeding resource availability. FRATS models these fundamental principles and should be considered for planning future aircraft transitions.

Existing manual planning methods are cumbersome, time-intensive, and do not provide detailed quantitative summaries of the schedules they create. FRATS can provide quantitative summaries of schedules created manually or evaluate the impact of changes to input data on existing schedules. Most importantly, in less time and with greater detail than existing methods, FRATS can use fundamental guidance to automatically create a training schedule that is optimal with respect to planning goals and planning priorities.

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APPENDIX A. SYLLABUS TEMPLATES

FRS and ATTU syllabus templates are created with the T&R syllabi [T&R8, 1999], MAWTS-1 syllabi [MAWTS, 2000], and prudent assessments of the amount of training a pilot can complete in a half-month segment. The FRS syllabi are guided by a specific sequence of training events that occasionally allows flexibility in scheduling. This permits modeling the FRS syllabus templates with FRS resource utilization and time-to-train assumptions.

A. FRS TEMPLATES

The FRS Cat1 and Cat2 syllabus templates are the same. At the beginning of the transition, the FRS will train all new V-22 pilots with the same syllabus, regardless of previous flight experience. As the FRS gains more familiarity with tilt-rotor flight, the FRS may change the Cat2 syllabus (a syllabus for experienced pilots) to address the needs of experienced pilots that differ from those of a basic pilot just out of flight school.

At the beginning of the V-22 transition, instructor pilots will complete the entire transition syllabus prior to commencing the instructor syllabus. After several years, fleet pilots will return to the FRS to instruct and will only require instructor training. In the baseline scenario, FRATS uses a *Cat5a* syllabus to model instructor requirements from FY 2001 to the end of FY 2005. The Cat5a syllabus is the same as the Cat1 and Cat2 syllabi during the first eight segments, with the Cat5 (Instructor Under Training) syllabus appended to the end. The Cat5b syllabus is the unadulterated Cat5 syllabus from T&R8.

A FRS syllabus template consists of a sequence of half-month segments. Each segment contains anticipated FRS resource usage (i.e., aircraft flight hours, simulator hours, and instructor pilot flights) for that segment of the syllabus. We provide Table 1 to document the syllabus events at the end of each segment. Table 2 documents the resource utilization associated with this partitiopn of the syllabus. The FRS syllabus templates for the baseline scenario were derived from TCCD based on the most recent Training and Readiness Manual and analysis conducted with the help of VMMT-204 Operations Department.

	Syllabus Segment Index									
Syllabus	1	2	3	4	5	6	7	8	9	10
cat1	IMI	s101	s110	119	136	153	173	191	193	
cat2	IMI	s101	s110	119	136	153	173	191	193	
cat3	s109	134	153	183	193					
cat4	136	193								
cat5a	IMI	s101	s110	119	136	153	173	191	505	511
cat5b	505	511								

Table A-1. Events at the End of Each Segment of the FRS Syllabi

Rows indicate FRS syllabus, and column labels indicate the syllabus segment. The table entries are the flight number of the last training event required in the syllabus segment. For instance, Segment 5 of the Cat1 syllabus ends with training event number 136, which corresponds to an instrument evaluation flight.

		Syllabus segment index (half-month period)										
Resource	**Syllabus**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Tot**
achrs	cat1	0	0	0	11.5	7	6	5	7	3.5		40
	cat2	0	0	0	11.5	7	6	5	7	3.5		40
	cat3	0	6.5	10	8.5	3.5						28.5
	cat4	5	6.5									11.5
	cat5a	0	0	0	11.5	7	6	5	7	6	3.5	46
	cat5b	2.5	3.5									6
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Tot**
simhrs	cat1	0	4	18	4	12	8	12	7			65
	cat2	0	4	18	4	12	8	12	7			65
	cat3	10	8	2	4	1						25
	cat4	12	9									21
	cat5a	0	4	18	4	12	8	12	7	8	6	79
	cat5b	8	6									14
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Tot**
Instr evts	cat1	0	0	0	7	4	4	3	4	2		24
	cat2	0	0	0	7	4	4	3	4	2		24
	cat3	0	4	6	5	2						17
	cat4	3	4									7
	cat5a	0	0	0	7	4	4	3	4	4	2	28
	cat5b	2	2									4

Table A-2. Aircraft Hours, Simulator Hours, and Instructor Events Required for Each Segment of Each FRS Syllabus Templates

Table A-2 lists the resource units (aircraft hours, simulator hours, and instructor events) for each segment (column label) of each FRS syllabus (row label). For example, Segment 4 of the Cat1 syllabus requires 11.5 aircraft hours, 4 simulator hours, and 7 instructor events. This table defines the FRS syllabus templates that are used in the baseline scenario.

B. ATTU TEMPLATES

The ATTU training program is far less regimented. Uncertainties in resource utilization in each ATTU syllabus and uncertainties in ATTU resource availability make FRS-style syllabus templates unattractive for modeling the ATTU. Furthermore, the uncertainties may lead to results that obscure salient results from the FRS scheduling model requested by Marine planners. For this reason, FRATS models ATTU training with time-to-train templates and does not incorporate resource utilization.

T&R8 identifies 11 flight leadership and instructor designations that must be attained in the ATTU for a squadron to be core competent during initial transition. Many designations require other designations as prerequisites, so an ATTU syllabus is constructed by adding training events appropriate for the designation to the end of the copilot core competency syllabus. Table A-3 is an excerpt from a table of ATTU requirements for each pilot. An "X" represents a required training event for the pilot to achieve a designation. Pilots 1 and 2 have Xs for each of the training events required for Air Mission Commander designation, to include Night Systems Instructor designation. Pilots 3 and 4 represent pilots pursuing Night Systems Instructor designation, in addition to prerequisite designations. Together, Pilots 1-4 meet the requirement for four Night Systems Instructors for a squadron to be core capable. Similarly, Pilots 5-12 train for designations ranging from Tilt-rotor Aircraft Commander to Division Leader. Pilots 13-16 represent those pilots trained to minimum levels of copilot core competency.

VMMT-204 approximated the time-to-train for each of the designations using a daily ATTU training schedule (VMMT-204, 2000). The ATTU schedule expects pilots to complete two training events per day several times during ATTU training. VMMT-204 estimates pilots will complete the ATTU1 and ATTU2 syllabi in eight periods (four months), the ATTU3 syllabus in seven periods, and the ATTU4 syllabus in six periods. Although ATTU2 and ATTU1 have the same number of segments, FRATS uses four ATTU groups to accommodate future modifications to the ATTU syllabus groups, if necessary.

	ATTU Syllabus Segment Index																						
ATTU Pilot	6		7										8										Total Events
Pilot 1 (ATTU1)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	83
Pilot 2 (ATTU1)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	83
Pilot 3 (ATTU2)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						75
Pilot 4 (ATTU2)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						75
Pilot 5 (ATTU3)	x	x	x	x	x	x	x	x	x	x													68
Pilot 6 (ATTU3)	x	x	x	x	x	x	x	x	x	x													68
Pilot 7 (ATTU3)	x	x	x	x	x																		63
Pilot 8 (ATTU3)	x	x	x	x	x																		63
Pilot 9 (ATTU3)	x	x	x	x	x																		63
Pilot 10 (ATTU3)	x	x	x	x	x																		63
Pilot 11 (ATTU3)	x	x	x	x	x																		63
Pilot 12 (ATTU3)	x	x	x	x	x																		63
Pilot 13 (ATTU4)	x	x																					60
Pilot 14 (ATTU4)	x	x																					60
Pilot 15 (ATTU4)	x	x																					60
Pilot 16 (ATTU4)	x	x																					60

Table A-3. ATTU Pilots and the Syllabus Groups

The leftmost column of Table A-3 enumerates 16 ATTU pilots and the ATTU syllabus to which each is assigned. In the cells to the right of each pilot, an 'X' represents a training event. The 'Total' column indicates how many flight events that pilot requires in order to complete the ATTU syllabus. Pilots 1 and 2 are expected to complete 83 events in eight half-month segments. Pilots 3 and 4 are expected to complete 75 events in eight half-month segments. The time-to-train calculation assumes ATTU pilots will complete approximately ten training events per segment.

APPENDIX B. GOALS AND PENALTIES

A. OVERVIEW

FRATS uses goal-programming to create a schedule that satisfies operational and manpower goals for the V-22 transition. These goals have priorities based upon transition guidance and inherent priorities that FRATS must model. FRATS models these priorities with a user-defined penalty scheme that assigns higher penalties to the least acceptable outcomes and lower penalties to less egregious deviations from requirements and goals. Penalty units are *penalty points per pilot deviation.*

FRATS seeks a solution (i.e., training schedule) that minimizes the total penalty induced by the schedule's deviations from the input goals and requirements. Penalties have relationships *between* goal groups (e.g., manpower vs. operational goals) and *within* goal groups (e.g., USMC manpower vs. USAF manpower). Table B-1 lists the penalties used in the baseline scenario. The following sections contain an explanation of the priorities and the associated penalties.

A clear priority between the Marine Corps and Air Force makes the FRATS results more tractable. Because Air Force and Marine pilots follow the same syllabi, the priority helps the user understand scheduling assignments when a resource conflict exists between two pilots requiring the same FRS syllabus training. In the baseline scenario, Marine Corps pilots are given the higher priority because Marine deployment schedules are inflexible, and unit transitions are driven by the deployment schedule. Fleet pilots must begin training in a small window in order to complete training during the delivery window, and FRATS does not allow a fleet pilot to be scheduled for training unless he can complete during his unit's window. Air Force pilots can train any time there are available resources. Because Marine and Air Force pilots follow the same syllabus, planners may modify the schedule, if necessary, without affecting resource utilization.

Goal	Model Result	Index	Penalty
GAR	Surplus	1	0.5
	Deficiency	2	4
AFPTR - Cum Cat1 and Cat2	Surplus	3	10
	Deficiency	4	3
USMC PTR	Surplus	5	0.5
	Deficiency	6	2
AFPTR - Annual Cat1 and Cat2	Surplus	7	8
	Deficiency	8	2.5
AFPTR - Quarterly	Deficiency	9	1.5
IP Manning	Surplus	10	0.5
	Deficiency	11	25
Core Competency	ATTU Deficiency	12	20
	ExpCopilot Deficiency	13	10
	Basic Copilot Deficiency	14	15
	Late from ATTU	15	1
Replenishment	Exp Deficiency	16	8
	Basic Deficiency	17	9

Table B-1. Transition Goals, Possible Deviations from Goals, and the Deviation Penalties - Baseline Scenario

FRATS creates optimal schedules by minimizing the cumulative penalties assessed for deviating from operational and manpower goals. Goal categories are in the left-hand column of Table B-1. A description of possible deviations from the goals is in the second column. The third column contains a reference index for the sections that follow. The fourth column shows the penalties assessed for each deviation. For example, each unit has core competency goals: completion of ATTU training on time, training all required ATTU pilots on time, training all required experienced co-pilots, and training all required basic co-pilots. A 1-point penalty is assessed for each pilot that completes ATTU training during the late portion of the delivery window, and a 20-point penalty is assessed for each ATTU pilot that is not scheduled for training.

B. MANPOWER GOALS AND PENALTIES

The first eleven penalties (indexes 1-11) in Table B-1 correspond to manpower goals. They are:

- penalties for a surplus or deficit of Marine Corps V-22 pilots with respect to annual GAR goals (indexes 1-2);
- penalties for a surplus or deficit of Air Force pilots with respect to cumulative Air Force training goals (indexes 3 and 4);

- penalties for a surplus or deficit of pilots with respect to annual Marine Corps PTR requirements (indexes 5 and 6);
- penalties for a surplus or deficit with respect to Air Force training requirements each year and each quarter (indexes 7-9); and
- penalties for a surplus or deficit with respect to instructor pilot manning levels at the FRS each half-month period (indexes 10 and 11).

The Air Force does not have explicit cumulative goals, but does want Air Force pilots spread evenly throughout the year. In order to motivate persistence (Brown, et al., 1997) and uniform training in each quarter, FRATS calculates quarterly and cumulative annual Air Force PTR goals and penalizes deviations from the goals. Surplus and deficiency deviations from the goal incur a penalty in order to keep the FRATS schedule oriented with the proposed plan.

The relative penalty weight of a deficiency indicates the relative priority of the goal. A higher deficiency penalty for a particular goal assigns a higher priority to the pilot that is required for that goal to be satisfied. For instance, the high penalty weight for a deficiency in instructors at the FRS (see Table B-1, index 11) indicates that FRS instructors are the single highest priority pilot. Instructor deviations are calculated each half-month period, so a deficiency accumulates large penalties if it remains over several periods. Similarly, Marine Corps GAR goals have priority of cumulative Air Force goals, and Marine Corps PTR goals have priority over Air Force PTR goals.

Penalties may combine in interesting ways. Suppose the Marine Corps has met its PTR goal for a given year but is one pilot short of the GAR goal, and the Air Force is one pilot short of its cumulative and annual PTR goals. If the remaining resources only allow one pilot to be trained, FRATS will schedule the Air Force pilot to avoid a combined penalty of 5.5 points (2.5 for PTR deficiency [index 8] and 3 for cumulative PTR deficiency [index 4]) and accept the penalty for a USMC GAR deficiency of 4 points (index 2).

For each of the manpower goals (which include instructor manning goals), FRATS calculates surplus and deficit deviations for each time epoch over which the goal

applies (e.g., annual, quarterly, etc.). High deficit penalties and low surplus penalties have the following combined effect in the baseline model: low surplus penalties motivate FRATS to schedule training in anticipation of future goals to prevent future deficits, which are heavily penalized. High surplus penalties and low deficit penalties have the opposite effect: FRATS is motivated to accept a low deficit penalty rather than train a pilot earlier than required and incur a high surplus penalty.

C. OPERATIONAL GOALS AND PENALTIES

With regard to FRS training, the primary Marine Corps operational goals for the V-22 transition are to provide enough trained pilots at the right time to meet initial core competency requirements for a transitioning squadron (See Table B-1, indexes 12 –15.) and to meet post-deployment pilot replenishment requirements (See Table B-1, indexes 16 and 17.). Operational priorities are ATTU pilots, basic copilots for transition, experienced copilot for transition, basic copilots for replenishment, and experienced copilots for replenishment, in order of decreasing priority. The baseline penalties reflect these priorities with descending penalties assessed for deficiencies of these pilot types.

There is no motivation for training surplus pilots for a specific squadron, so FRATS does not allow surplus pilot production for fleet units. FRATS calculates deficiencies with elastic variables for each transition or post-deployment replenishment and assesses a penalty for each pilot deficiency in the FRATS schedule.

D. DISCOUNTING AND FUTURE UNCERTAINTY

FRATS prioritizes near-term requirements over future requirements by discounting penalties five percent per year. The modeling assumptions will change over time, and the model should focus on the near-term plan for which the assumptions are most likely to be valid.

For similar reasons, FRATS allows continuous *COHORT* variables after the first five years of the planning horizon. The model parameters are likely to change over time, thus an integer schedule for training five years hence is unlikely to remain intact. Continuous variables reduce the effort (time) required by the optimization software and provide acceptably accurate results that the user may round at his discretion.

E. UTILITY THEORY

One may dissect the penalty scheme using utility theory and derive sets of outcomes to which planners are indifferent [Marshall, Oliver, 1995, pp. 232-250]. For example, consider a penalty scheme (no discounting) with a deficiency penalty of D, which is higher than a surplus penalty of S. This implies that the planner is indifferent to a surplus of one pilot carried for S/D years when compared to a deficit of one pilot for one year.

A second example illustrates the planner's indifference equivalence between ATTU and replenishment pilots. An ATTU deficiency penalty of A and a replenishment deficiency penalty of R indicates the planner feels an ATTU pilot is worth A/R replenishment pilots. Given limited resources, the planner would schedule the ATTU pilot only if doing so displaced fewer than A/R replenishment pilots.

FRATS solves a sequence of two optimization models to produce each final training plan. The former minimizes penalties, and then the latter maximizes the number of excess Cat1 pilots that can be scheduled with the remaining resources. This strict hierarchy implies that there is *no* equivalent value of a notional excess pilot compared to a real pilot scheduled to meet a requirement. FRATS makes no tradeoffs between excess pilots. This ensures that excess capacity is considered only *after* the optimal schedule is found.

Utility theory is not applicable for all subsets of FRATS penalties. For instance, if ATTU deficiencies and Air Force annual training surpluses are both penalized the same, it would be illogical to try to establish a relationship between the two outcomes. The ATTU deficiency is an act of omission (under-scheduling a requirement), and the Air Force surplus is an act of commission (over-scheduling), so the model never faces a choice of one penalty or the other. FRATS simply schedules the ATTU pilot and avoids a surplus penalty.

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APPENDIX C. INPUT DATA SPREADSHEETS

FRATS gets input data from pre-formatted Excel spreadsheets. (See Figures C-1 through C-5.) The spreadsheets are divided into five data categories: Operational Data, VMMT-204 Data, Syllabus Data, Manpower Data, and Penalty Data. The cells that accept input data are shaded light green.

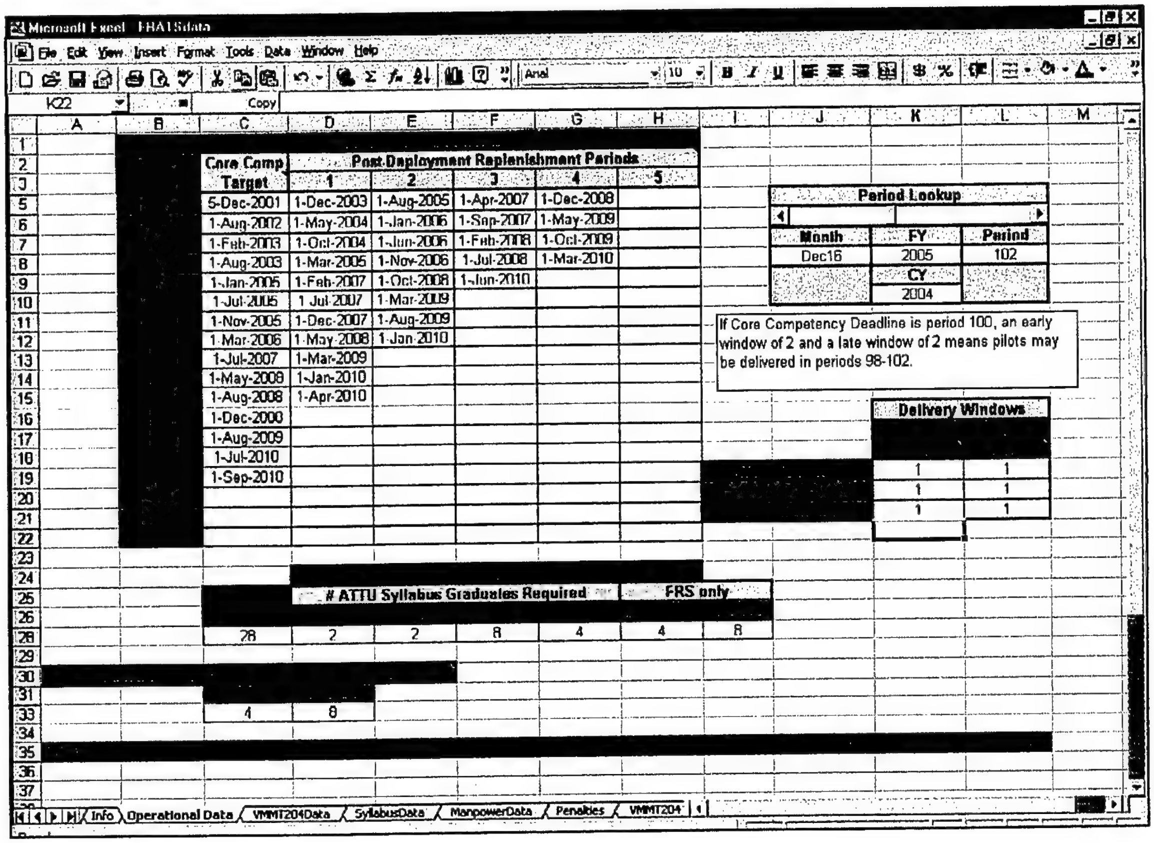


Figure C-1. Operational Data Spreadsheet

The Operational Data spreadsheet accepts core competency deadlines and post-deployment replenishment dates and converts them to an appropriate half-month index. A slider bar is provided to convert period indexes to calendar and fiscal year dates, if necessary. The operational data accepts unit templates for core competency and post-deployment replenishment. Text boxes provide examples, and comment boxes are available to explain data requirements. In the baseline scenario, squadrons VMM-264 through VMM-364 are scheduled for transition between FY 2001 and FY 2010. Other squadrons are included in the Operational Requirements table for possible use when modeling other scenarios.

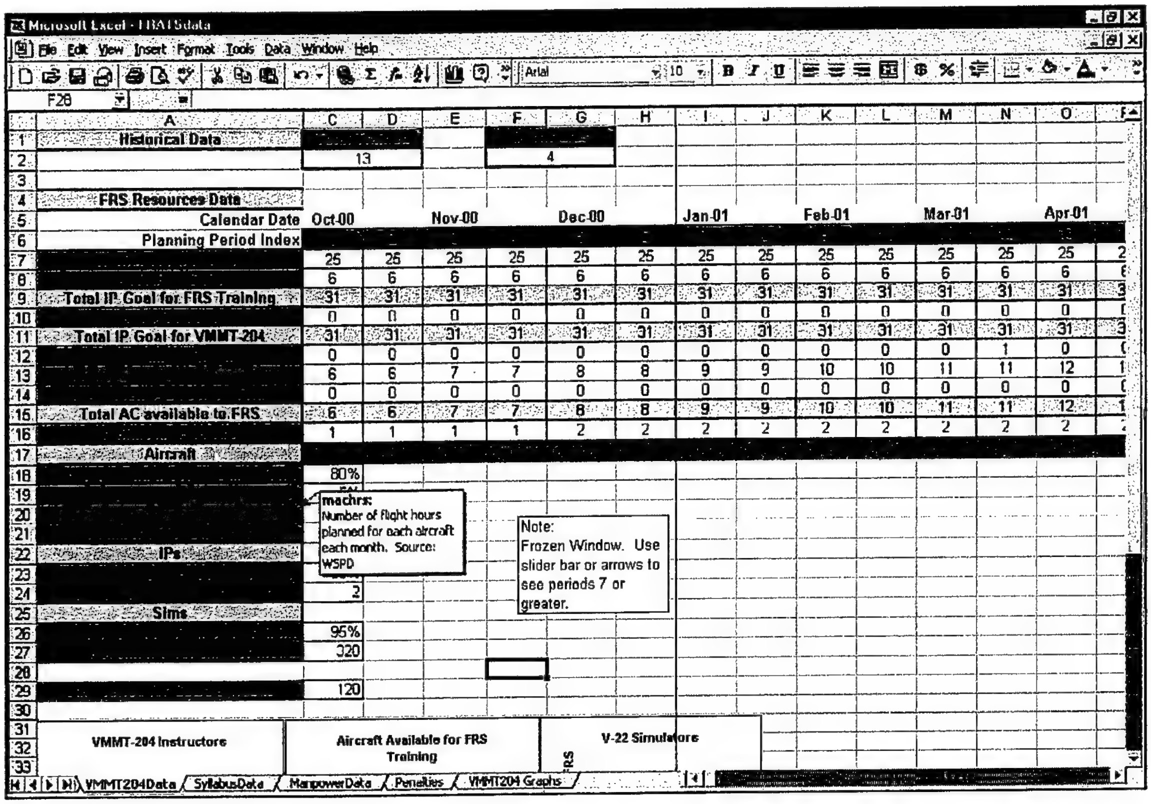
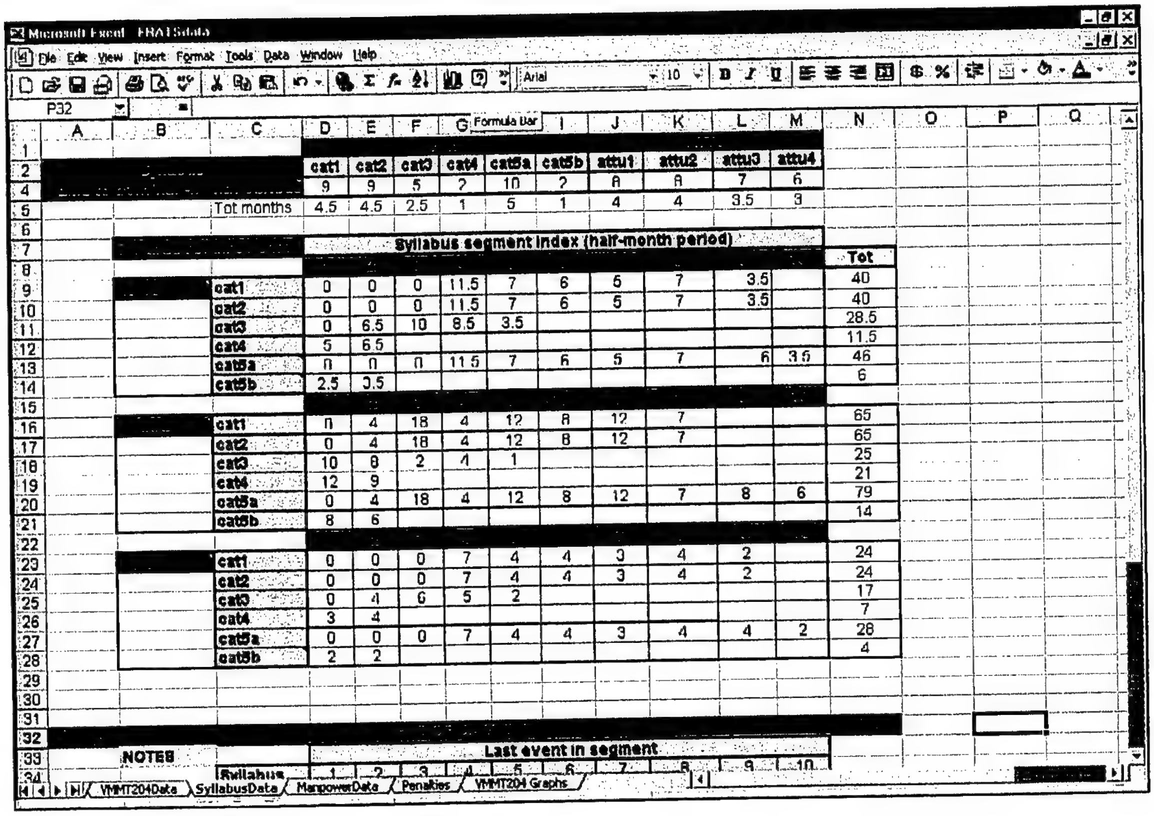


Figure C-2. VMMT-204 Data Spreadsheet

The VMMT-204 Data spreadsheet accepts data about FRS resources and FRS availability. The spreadsheet requires data for each period of the 240 periods in FY 2001 through FY 2010. The user may scroll down to charts below the table (the tops are visible in this view) for a visual representation of the ten-year resource availability. This helps the user to identify data entry mistakes without checking each the 240 periods for accuracy. Text boxes and comment boxes are included to explain data requirements. The two green boxes at the top of the screen indicate that 13 V-22 pilots have been trained prior to October 2000, and four of them have left VMMT-204 for other assignments. This is 16 fewer instructors than the desired goal of 25, found in row 7 column c of the Excel spreadsheet. Frozen window frames allow the user to view data for later periods without losing the row titles for the data.



	cat1	cat2	cat3	cat4	cat5a	cat5b	attu1	attu2	attu3	attu4	
	9	9	5	2	10	2	8	8	7	6	
Tot months	4.5	4.5	2.5	1	5	1	4	4	3.5	3	
	Syllabus segment index (half-month period)										**Tot**
cat1	0	0	0	11.5	7	6	5	7	3.5		40
cat2	0	0	0	11.5	7	6	5	7	3.5		40
cat3	0	6.5	10	8.5	3.5						28.5
cat4	5	6.5									11.5
cat5a	0	0	0	11.5	7	6	5	7	6	3.5	46
cat5b	2.5	3.5									6
cat1	0	4	18	4	12	8	12	7			65
cat2	0	4	18	4	12	8	12	7			65
cat3	10	8	2	4	1						25
cat4	12	9									21
cat5a	0	4	18	4	12	8	12	7	8	6	79
cat5b	8	6									14
cat1	0	0	0	7	4	4	3	4	2		24
cat2	0	0	0	7	4	4	3	4	2		24
cat3	0	4	6	5	2						17
cat4	3	4									7
cat5a	0	0	0	7	4	4	3	4	4	2	28
cat5b	2	2									4

NOTES

	Last event in segment									
Syllabus	1	2	3	4	5	6	7	8	9	10

Figure C-3. Syllabus Data Spreadsheet

The Syllabus Data spreadsheet contains the FRS and ATTU syllabus templates. The time-to-train requirements for each syllabus are listed at the top of the screen. In the syllabus requirements table in the middle of the screen, each FRS syllabus template is listed with the aircraft hour, simulator hour, and instructor events required for each segment of the syllabus. For example, the Cat1 syllabus requires 11.5 aircraft hours, 4 simulator hours, and 7 instructor events in Segment 4. Syllabus totals are provided in each of the tables to highlight discrepancies with T&R8 and other possible mistakes. In the spaces below the data table, a "Notes" table (cut off in this view) is created for recording the flight event number for the last flight of each syllabus segment for each FRS template.

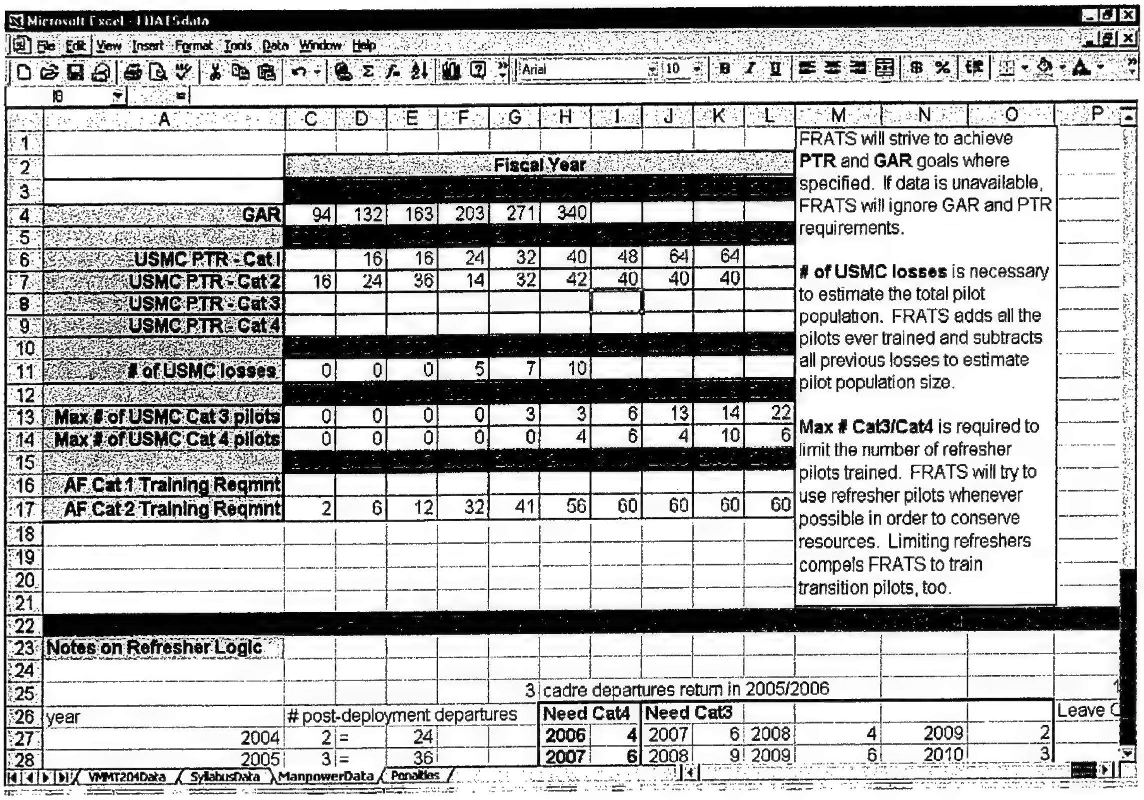
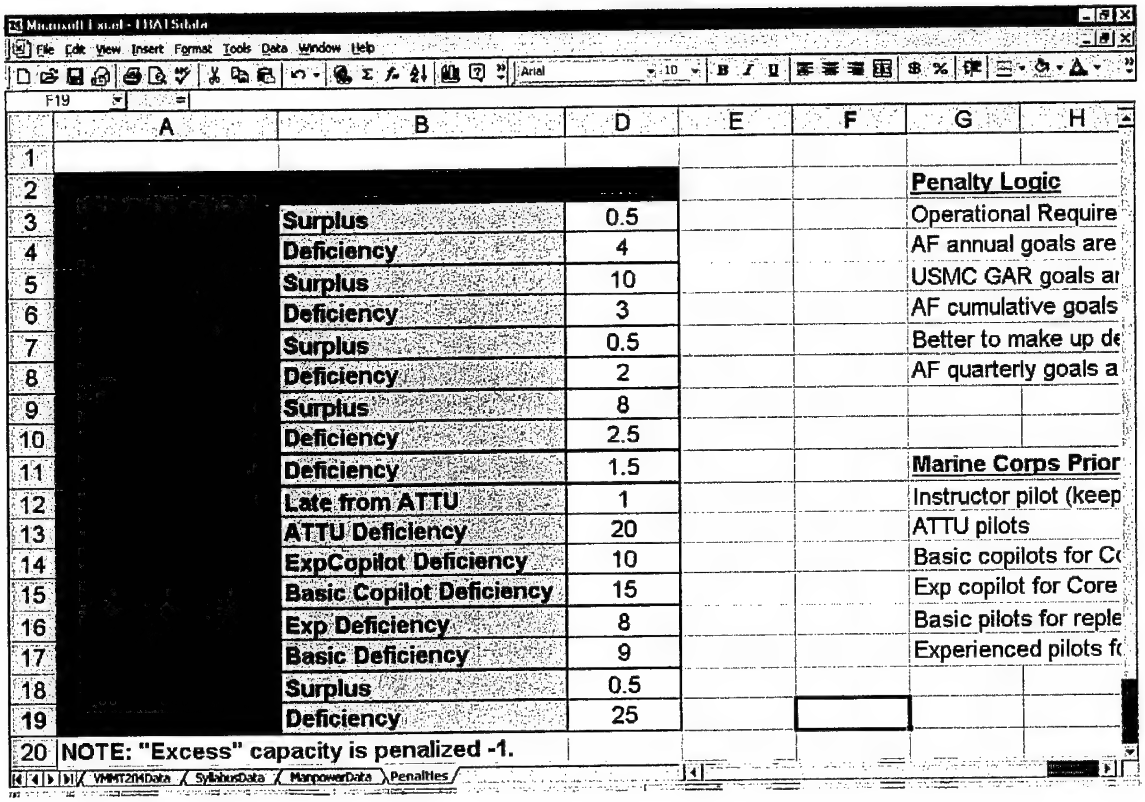


Figure C-4. Manpower Data Spreadsheets

The Manpower Data spreadsheet accepts data reflecting manpower goals over the planning horizon. Marine Corps GAR and Marine Corps PTR goals may be entered for each fiscal year in the upper portion of the table. Some data, such as USMC GAR and expected annual losses, are only available up to FY 2006. If a data entry cell is left blank, FRATS disregards the cell and does not consider the data when creating schedules and assessing penalties in the objective function. For example, Marine Corps GAR for FY 2006 is 340 pilots, so FRATS will penalize any deviation from that goal. However, there is no data entry for GAR for FY 2007, so FRATS will not consider the goal when creating the optimal schedule. At present, the Air Force has no Cat1 training requirement, so these cells are also left blank. In the area below the bar across row 22, a table (cut off in this view) is available for data calculations, if necessary. The text box provides explanatory information, and comments are inserted in several cells for reference.



	A	B	D	E	F	G	H
1							
2						**Penalty Logic**	
3		**Surplus**	0.5			Operational Require	
4		**Deficiency**	4			AF annual goals are	
5		**Surplus**	10			USMC GAR goals ar	
6		**Deficiency**	3			AF cumulative goals	
7		**Surplus**	0.5			Better to make up de	
8		**Deficiency**	2			AF quarterly goals a	
9		**Surplus**	8				
10		**Deficiency**	2.5				
11		**Deficiency**	1.5			**Marine Corps Prior**	
12		**Late from ATTU**	1			Instructor pilot (keep	
13		**ATTU Deficiency**	20			ATTU pilots	
14		**ExpCopilot Deficiency**	10			Basic copilots for Co	
15		**Basic Copilot Deficiency**	15			Exp copilot for Core	
16		**Exp Deficiency**	8			Basic pilots for reple	
17		**Basic Deficiency**	9			Experienced pilots fo	
18		**Surplus**	0.5				
19		**Deficiency**	25				
20	**NOTE: "Excess" capacity is penalized -1.**						

Figure C-5. Penalty Data Spreadsheet

The Penalty Data spreadsheet accepts penalty assignments as described in Appendix B. A blank penalty is the same as no penalty. The penalties in the table above are those used in the baseline scenario, with the supporting logic typed in the space to the right (cut off in this view). For a detailed explanation of the penalties and supporting logic, see Appendix B.

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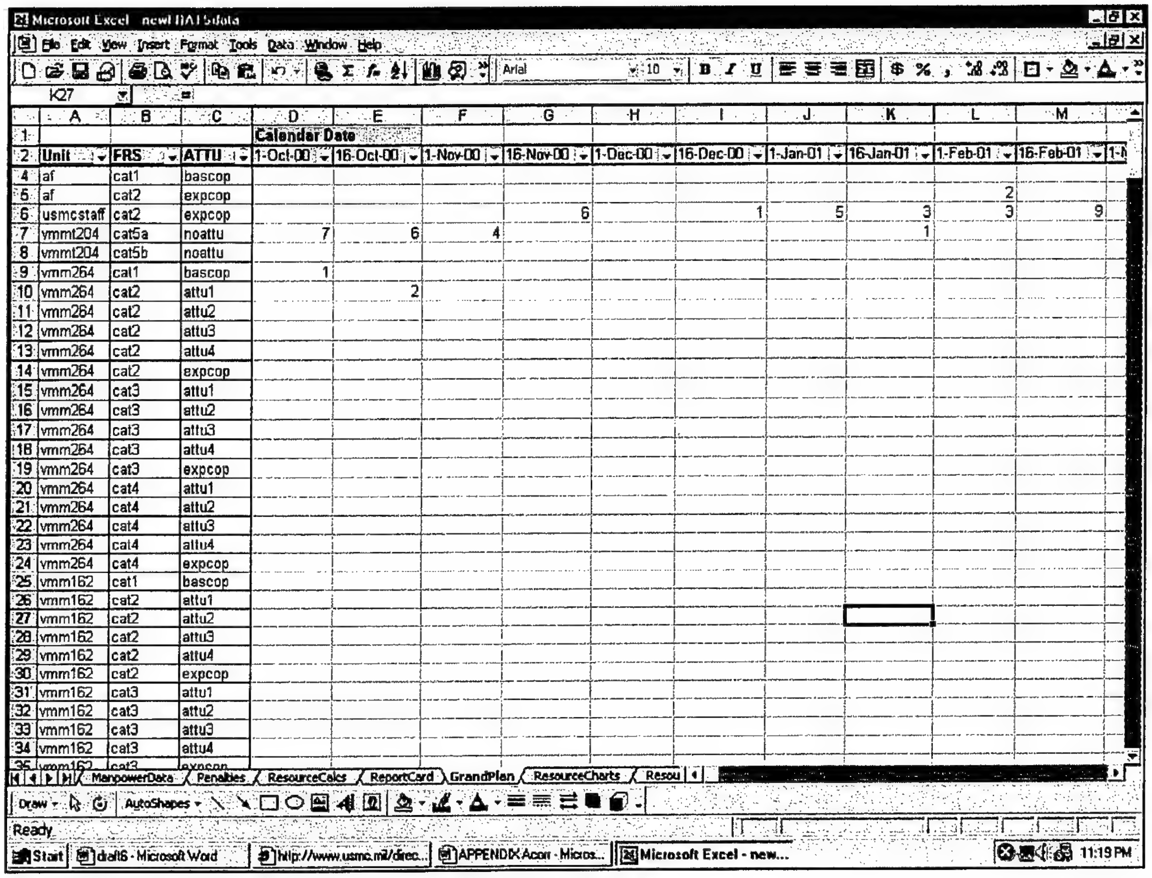
APPENDIX D. SOLUTION OUTPUT SPREADSHEETS

The FRATS output spreadsheets display the FRS training schedule, resource utilization induced by the schedule, and goal status for display in tables and charts. There are four principal spreadsheets: the Master Schedule spreadsheet displaying the entire FRS training schedule, a Report Card spreadsheet comparing FRATS results with manpower and operational goals, a Resource Plan spreadsheet displaying the resources used by the schedule, and a FRS Total spreadsheet reporting FRS classes and their start dates. (See Figures D-1 through D-5.)

When used with the General Algebraic Modeling System (GAMS), FRATS outputs the optimal FRS schedule in the Master Schedule spreadsheet. The Resource Plan spreadsheet automatically calculates the resource usage based on the Master Schedule, and the Report Card spreadsheet automatically calculates PTR and GAR data based on the Master Schedule. GAMS outputs the Transition Deficiencies and Replenishment Deficiencies to the Report Card spreadsheet. GAMS also outputs the excess capacity schedule in the FRS Total spreadsheet.

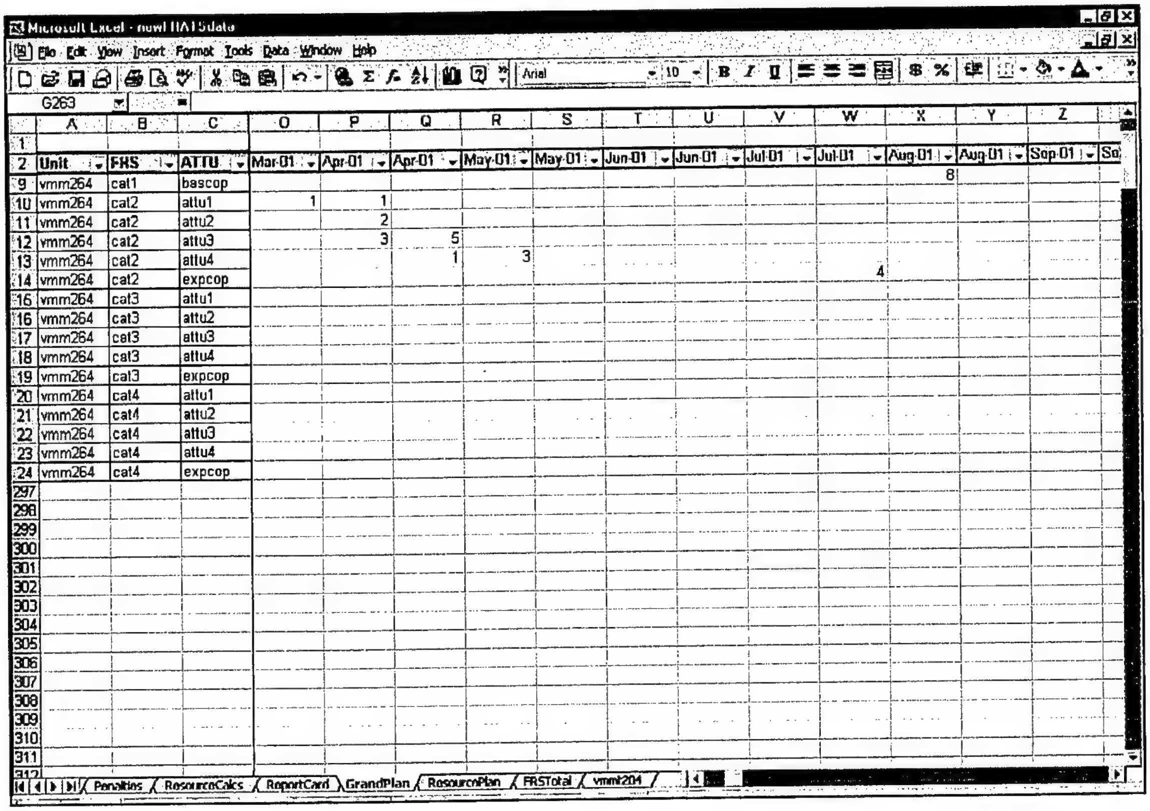
As a manual planner, FRATS allows changes to the input data and the Master Schedule spreadsheet. The Resource Plan spreadsheet, FRS Total spreadsheets (except excess capacity), and GAR and PTR data in the Report Card spreadsheet recalculate after any change of this nature. The following data does not update automatically after a manual change: Transition Deficiency tables, Replenishment Deficiency tables, and Late to Core Competency tables in the Report Card spreadsheet; and excess capacity schedule in the FRS Total spreadsheet.



	Unit	FRS	ATTU	1-Oct-00	16-Oct-00	1-Nov-00	16-Nov-00	1-Dec-00	16-Dec-00	1-Jan-01	16-Jan-01	1-Feb-01	16-Feb-01
4	af	cat1	bascop										
5	af	cat2	expcop									2	
6	usmcstaff	cat2	expcop				6		1	5	3	3	9
7	vmmt204	cat5a	noattu	7	6	4					1		
8	vmmt204	cat5b	noattu										
9	vmm264	cat1	bascop	1									
10	vmm264	cat2	attu1		2								
11	vmm264	cat2	attu2										
12	vmm264	cat2	attu3										
13	vmm264	cat2	attu4										
14	vmm264	cat2	expcop										
15	vmm264	cat3	attu1										
16	vmm264	cat3	attu2										
17	vmm264	cat3	attu3										
18	vmm264	cat3	attu4										
19	vmm264	cat3	expcop										
20	vmm264	cat4	attu1										
21	vmm264	cat4	attu2										
22	vmm264	cat4	attu3										
23	vmm264	cat4	attu4										
24	vmm264	cat4	expcop										
25	vmm162	cat1	bascop										
26	vmm162	cat2	attu1										
27	vmm162	cat2	attu2										
28	vmm162	cat2	attu3										
29	vmm162	cat2	attu4										
30	vmm162	cat2	expcop										
31	vmm162	cat3	attu1										
32	vmm162	cat3	attu2										
33	vmm162	cat3	attu3										
34	vmm162	cat3	attu4										

Figure D-1. FRATS Master Training Schedule (Grand Plan) Spreadsheet

FRATS outputs the entire FRATS schedule in the Grand Plan spreadsheet. *COHORT*s are identified by unit, FRS schedule, ATTU syllabus, and the period in which training begins. For example, 6 pilots from VMMT-204 begin Cat5a training in the period that begins 16 October. The Master Schedule accepts manual data entry in addition to data exported by the FRATS optimization model. In this manner, planners may manually adjust FRATS plans, if required.



Microsoft Excel - newl HAI5data

	A	B	C	O	P	Q	R	S	T	U	V	W	X	Y	Z
1															
2	Unit	FRS	ATTU	Mar-01	Apr-01	Apr-01	May-01	May-01	Jun-01	Jun-01	Jul-01	Jul-01	Aug-01	Aug-01	Sep-01
9	vmm264	cat1	bascop										8		
10	vmm264	cat2	attu1	1	1										
11	vmm264	cat2	attu2		2										
12	vmm264	cat2	attu3		3	5									
13	vmm264	cat2	attu4			1	3								
14	vmm264	cat2	expcop									4			
16	vmm264	cat3	attu1												
16	vmm264	cat3	attu2												
17	vmm264	cat3	attu3												
18	vmm264	cat3	attu4												
19	vmm264	cat3	expcop												
20	vmm264	cat4	attu1												
21	vmm264	cat4	attu2												
22	vmm264	cat4	attu3												
23	vmm264	cat4	attu4												
24	vmm264	cat4	expcop												

Penalties / ResourceCalcs / ReportCard / GrandPlan / ResourcePlan / FRSTotal / vmm204

Figure D-2. FRATS Master Training Schedule Spreadsheet Using Excel Autofilter

The Master Schedule includes all of 291 possible unit, FRS syllabus, and ATTU syllabus groups and each of 240 possible half-month periods from FY 2001 to FY 2010. Excel Autofilter functions make this easier to manage. After pressing the little triangle in the Unit heading (in row 2 column A), the user may select the unit whose schedule he wants to see. All other units are screened out. In this way, it is easy to see a unit's schedule without distraction from other units.

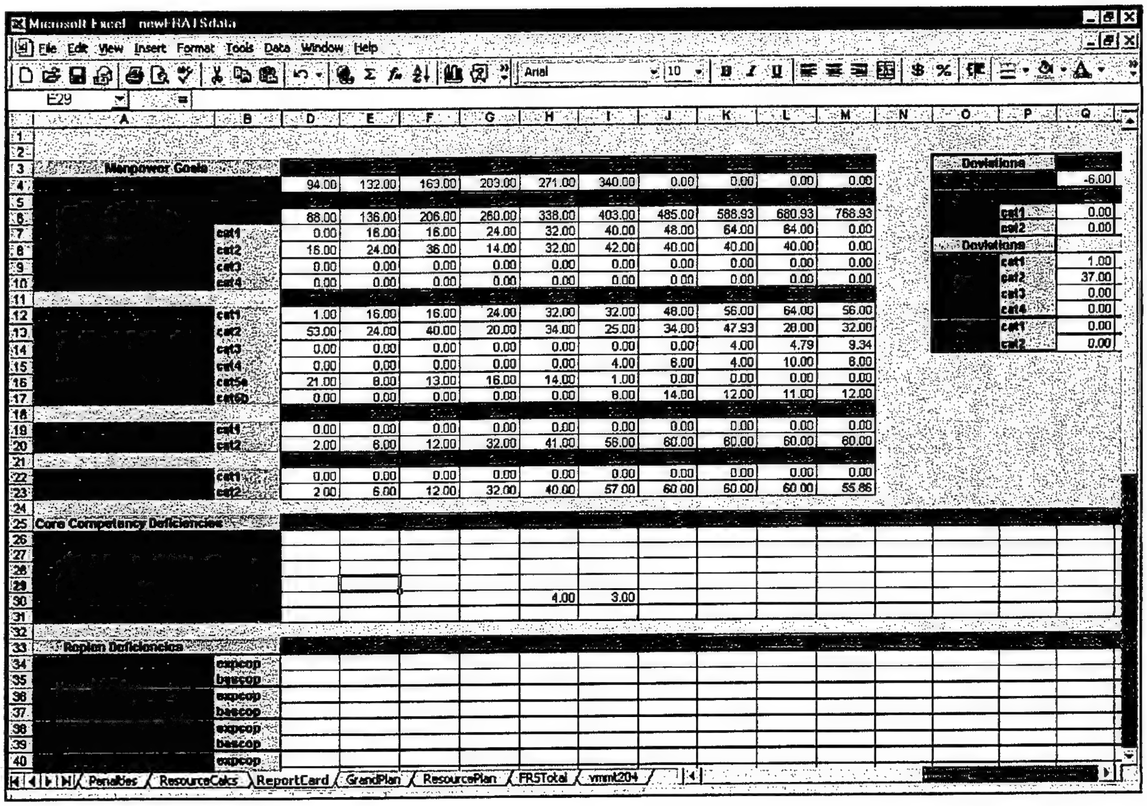
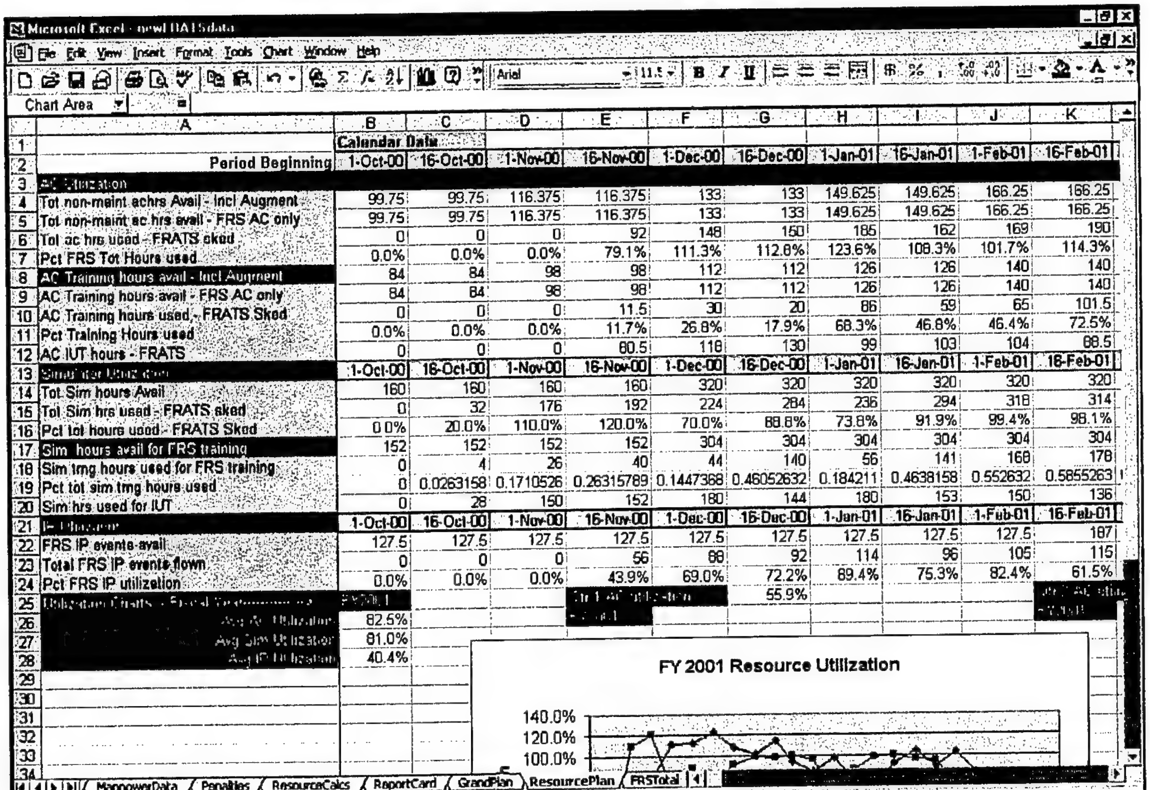


Figure D-3. FRATS Report Card Spreadsheet

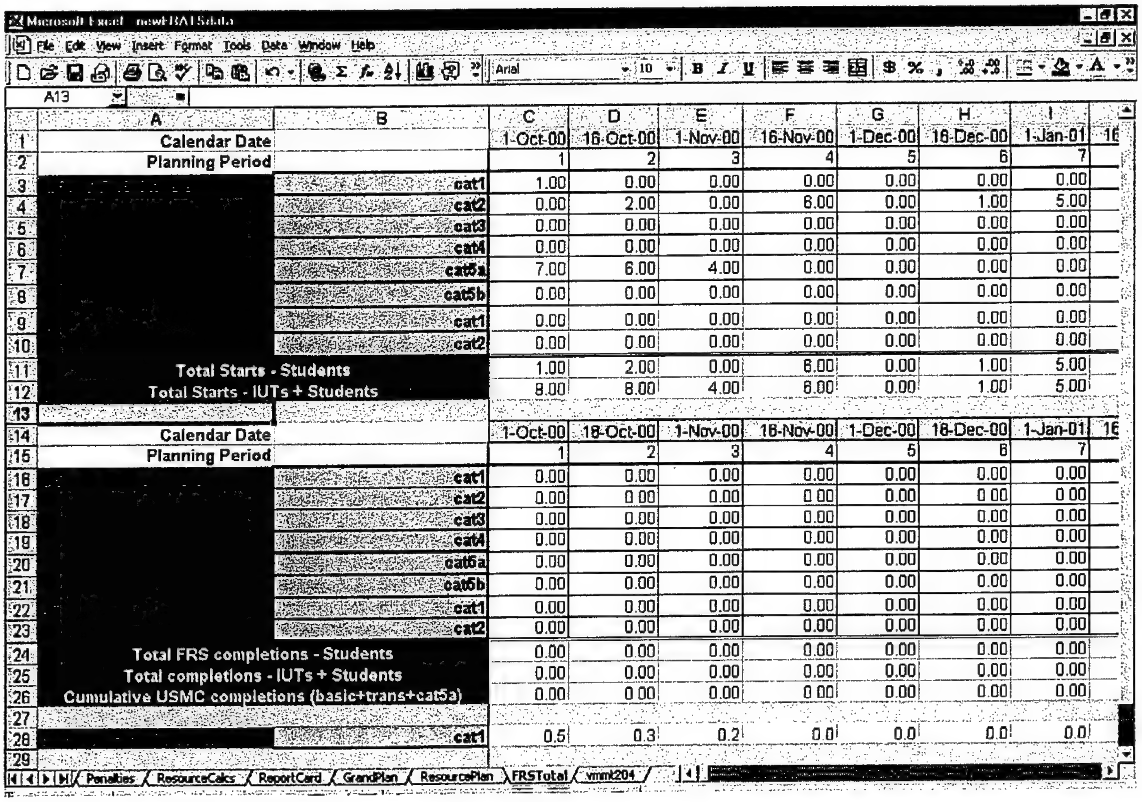
The FRATS Report Card spreadsheet automatically calculates GAR and PTR data for the schedule entered in the Master Schedule spreadsheet. The transition and replenishment deficiency data is output from GAMS and does not automatically update with manual entries in the Master Schedule. Data is also presented in charts below row 40 and to the right of column O (cut off in this view).



	A	B	C	D	E	F	G	H	I	J	K
1		Calendar Data									
2	Period Beginning	1-Oct-00	16-Oct-00	1-Nov-00	16-Nov-00	1-Dec-00	16-Dec-00	1-Jan-01	16-Jan-01	1-Feb-01	16-Feb-01
3	[illegible]										
4	Tot non-maint achrs Avail - Incl Augment	99.75	99.75	116.375	116.375	133	133	149.625	149.625	166.25	166.25
5	Tot non-maint ac hrs avail - FRS AC only	99.75	99.75	116.375	116.375	133	133	149.625	149.625	166.25	166.25
6	Tot ac hrs used - FRATS sked	0	0	0	92	148	150	185	162	169	190
7	Pct FRS Tot Hours used	0.0%	0.0%	0.0%	79.1%	111.3%	112.8%	123.6%	108.3%	101.7%	114.3%
8	AC Training hours avail - Incl Augment	84	84	98	98	112	112	126	126	140	140
9	AC Training hours avail - FRS AC only	84	84	98	98	112	112	126	126	140	140
10	AC Training hours used - FRATS Sked	0	0	0	11.5	30	20	86	59	65	101.5
11	Pct Training Hours used	0.0%	0.0%	0.0%	11.7%	26.8%	17.9%	68.3%	46.8%	46.4%	72.5%
12	AC IUT hours - FRATS	0	0	0	80.5	118	130	99	103	104	88.5
13	[illegible]	1-Oct-00	16-Oct-00	1-Nov-00	16-Nov-00	1-Dec-00	16-Dec-00	1-Jan-01	16-Jan-01	1-Feb-01	16-Feb-01
14	Tot Sim hours Avail	160	160	160	160	320	320	320	320	320	320
15	Tot Sim hrs used - FRATS sked	0	32	176	192	224	284	236	294	318	314
16	Pct tot hours used - FRATS Sked	0.0%	20.0%	110.0%	120.0%	70.0%	88.8%	73.8%	91.9%	99.4%	98.1%
17	Sim hours avail for FRS training	152	152	152	152	304	304	304	304	304	304
18	Sim trng hours used for FRS training	0	4	26	40	44	140	56	141	168	178
19	Pct tot sim trng hours used	0	0.0263158	0.1710526	0.26315789	0.1447368	0.46052632	0.184211	0.4638158	0.552632	0.5855263
20	Sim hrs used for IUT	0	28	150	152	180	144	180	153	150	136
21	[illegible]	1-Oct-00	16-Oct-00	1-Nov-00	16-Nov-00	1-Dec-00	16-Dec-00	1-Jan-01	16-Jan-01	1-Feb-01	16-Feb-01
22	FRS IP events avail	127.5	127.5	127.5	127.5	127.5	127.5	127.5	127.5	127.5	187
23	Total FRS IP events flown	0	0	0	56	88	92	114	96	105	115
24	Pct FRS IP utilization	0.0%	0.0%	0.0%	43.9%	69.0%	72.2%	89.4%	75.3%	82.4%	61.5%
25	[illegible]	[illegible]			[illegible]		55.9%				[illegible]
26	[illegible]	82.5%									
27	Avg Sim Utilization	81.0%									
28	[illegible]	40.4%									

Figure D-4. FRATS Resource Plan Spreadsheet

FRATS schedules induce resource utilization for each period, quarter, and fiscal year of the ten-year planning horizon, and the Resource Plan spreadsheet displays this data. The resource utilization tables are based upon the master schedule and the syllabus templates. A change in the master schedule, VMMT-204 data, or the syllabus templates will automatically change the resource utilization tables based upon the schedule in the Master Schedule (Grand Plan) spreadsheet. For example, if simulators were reduced to 3 in FY 2006, this data could be entered in the appropriate cells of the VMMT-204 Data spreadsheet, and the resource utilization induced by the Master Schedule would update automatically. In this way, planners may rapidly assess the effect of various changes on the existing schedule. In this view of the first few months of FY 2001, the tables indicate that no aircraft flight hours are scheduled until 16 Nov 2000 (see row 6 column E), and 55.9% of total aircraft hours are scheduled in the first quarter of FY 2001 (see row 25 column G). Visual charts (cut off in this view) of the data are below the tables.



	A	B	C	D	E	F	G	H	I
1	Calendar Date		1-Oct-00	16-Oct-00	1-Nov-00	16-Nov-00	1-Dec-00	16-Dec-00	1-Jan-01
2	Planning Period		1	2	3	4	5	6	7
3		cat1	1.00	0.00	0.00	0.00	0.00	0.00	0.00
4		cat2	0.00	2.00	0.00	6.00	0.00	1.00	5.00
5		cat3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6		cat4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7		cat5a	7.00	6.00	4.00	0.00	0.00	0.00	0.00
8		cat5b	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9		cat1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10		cat2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Total Starts - Students		1.00	2.00	0.00	6.00	0.00	1.00	5.00
12	Total Starts - IUTs + Students		8.00	8.00	4.00	6.00	0.00	1.00	5.00
13									
14	Calendar Date		1-Oct-00	16-Oct-00	1-Nov-00	16-Nov-00	1-Dec-00	16-Dec-00	1-Jan-01
15	Planning Period		1	2	3	4	5	6	7
16		cat1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17		cat2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18		cat3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19		cat4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20		cat5a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21		cat5b	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22		cat1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23		cat2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Total FRS completions - Students		0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Total completions - IUTs + Students		0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Cumulative USMC completions (basic+trans+cat5a)		0.00	0.00	0.00	0.00	0.00	0.00	0.00
27									
28		cat1	0.5	0.3	0.2	0.0	0.0	0.0	0.0

Figure D-5. FRATS FRS Total Spreadsheet

Data in the FRS Master Schedule spreadsheet is consolidated into a single table in the FRS Total spreadsheet. This spreadsheet reports the FRS schedule by syllabus and branch of service for each half-month period over the ten-year planning horizon. Additionally, the number of possible excess Cat1 starts is listed at the bottom of the table, based upon the last FRATS optimization run. <u>The EXCESS schedule does not update automatically to changes in any of the data</u>. With this consolidated schedule, V-22 planners have a concise representation of the Master Schedule.

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